Beyond High Definition: Emerging Display Technologies for the Warfighter

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ABSTRACT

Now that image generator hardware has become a Commercial Off –The-Shelf (COTS) commodity, visual system designers have been liberated to incorporate more and more realistic visual effects into their software Image Generators (IGs) and databases using the massively parallel architectures that modern Graphics Processing Units (GPU) platforms can provide. Display systems have not kept up the same pace of innovation, however. Although high definition television (HDTV) has revolutionized the consumer viewing experience, most training systems today are have projectors barely more resolution than the 1000 line custom built analog CRT projectors of a generation ago. The consumer world has now leapfrogged the simulation and training market and projectors approaching four times HD image content are now operating in many home theaters. This paper will focus on how these emerging technologies are being adopted to provide immersive visual training environments with up to eye-limited resolution and exhibiting affordability/reliability driven by the demands of the consumer marketplace and international broadcast standards. Analysis and test results will be presented to demonstrate that these new display methods greatly enhance the warfighter's ability to train critical visual tasks at incremental increases in life cycle cost.

ABOUT THE AUTHORS

Harry Streid is a visual systems engineer for Boeing Training Systems and Government Services (TS&GS). He develops flight simulation visual systems and designs large screen displays for these applications. He has been awarded numerous display related U.S. and foreign patents.

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Rod Sterling is Chief Engineer of JVC Technology Center. He received his MS in Electrical Engineering, Applied Physics from the University of California in San Diego. He has over 28 years experience in displays and display devices at JVC and Hughes Aircraft Co. He holds numerous U.S. and foreign patents.

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INTRODUCTION

Throughout the last decade the DoD's Dr Darrel Hoper (Hoper 2005) campaigned to draw attention to the limitations of then current display technology. To quote Dr. Hoper: "The DoD goal of maintaining informational superiority and situational dominance while reducing the forward combat footprint requires continual closing of the 1,000X gap between presently fielded warfighter interfaces and the capacity of the human visual system" In his 10 year roadmap for display development one of the goals he hoped to see attained was an ultra resolution 25 Megapixel display device and 300 Megapixel display systems. Such capability seemed in the realm of science fiction at the time when one-million pixel displays had just become widely available. In this paper we report that this goal is now close to being realized.

BACKGROUND

Current State of the Art and a Path Forward

Eight Megapixel projectors are now in use in full field of view training systems with 20/40 acuity. Coupled with the capability of these projectors to stimulate Night Vision Goggles, these systems are providing more training sorties in the simulator and at reduced cost. Extending visual performance to the next level would allow even more training tasks to be performed but support and acquisition costs must be controlled as defense budgets continue to decline. An upgrade path from today's HD (High Definition) visual systems is needed which can approach a 2X improvement in acuity without the 4X increase in number of projectors that a brute-force approach would require. One such a path forward leverages the Quad-HD LCOS (Liquid Crystal on Silicon) projectors used now on many simulator visual systems with a technique known as "e-Shift". E-Shift is a an application of display supersampling which has been described in (Damera 2009) as a method of providing high image quality. It uses a combination of image generation and display techniques that superimposes multiple frames from a single or multiple projectors to display alias free imagery beyond the Nyquist limit of the native projector.

Image Quality in CRT Displays

The transition from analog CRT to digital projectors for simulation and training applications is nearly complete and for the most part it has been successful. The newer technology is proving its worth in greater reliability and freedom from obsolescence woes as the sun sets on the workhorse CRT. The longevity of this analog technology was largely due to its ability to interface between the digital realm and the analog world of light and color as perceived by the human visual system. The CRT Gaussian spot shape played a critical role in maintaining image quality. As shown in figure 1, CRT displays had to be designed with significant overlap between raster lines in order to provide uniform brightness. Serendipitously, this overlap provided additional low-pass filtering which resulted in the characteristic smoothness we associate with CRT displays.

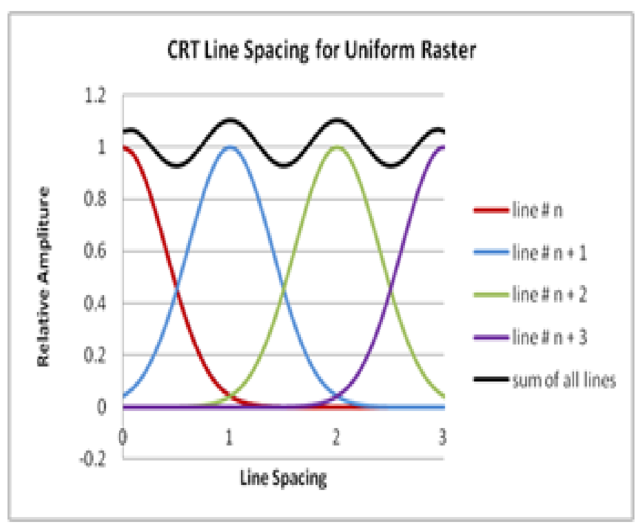

Figure 1 Characteristics of the CRT Beam Spot

Image Quality and Human Performance

Optimization of human performance is the goal in the development of a good visual display. Not surprisingly then, there are many parallels between a visual system used for a training system and a tactical display used on a modern weapons system. Since the 1950s the US Army Night Vision and Electronic Sensors Directorate (NVESD) has set the standards for man/machine interfaces of displays. One example is the ubiquitous use of DORI (Detection, Orientation, Recognition and Identification) criteria (Johnson 1958) to specify requirements for simulator visual systems. More recently (Devitt, Driggers, Volmerhausen 2001) have shown that in a sampled data system, image quality cannot be guaranteed by rule of thumb guidelines such as adherence to Nyquist criteria or Kell factors. As documented in human factors tests performed in Devitt, the probability of target recognition is a multivariate problem highly dependent upon the interaction between the reconstruction filter and sampling rate which can be quantified in a spurious response metric. Spurious response is defined as the product of the projector MTF with the first harmonic aliasing. It is another way of referring to the familiar "jaggies" commonly encountered in computer graphics, as illustrated in figure2.

Figure 2 Aliasing Is Inevitable in a Sampled-Data System

As discussed above, CRT projectors provided an additional Gaussian low pass filter which became part of the signal reconstruction process. Portrayed in the frequency domain in figure 3, the CRT reduces the amplitude of the spurious response (aliasing) caused by sampling effects in the image generator. Digital projectors have pixel apertures which are narrower and more rectangular than the CRT, resulting in a broader MTF. As a result they are more capable of displaying aliasing artifacts produced by the image generator and introduce some of their own as well. Figures 4 and 5 show that while the spurious response will be greater on a digital projector than a CRT, it can be minimized and allow the full resolution of the digital projector to be realized by increasing the sampling (pixel) rate by a factor of 2.

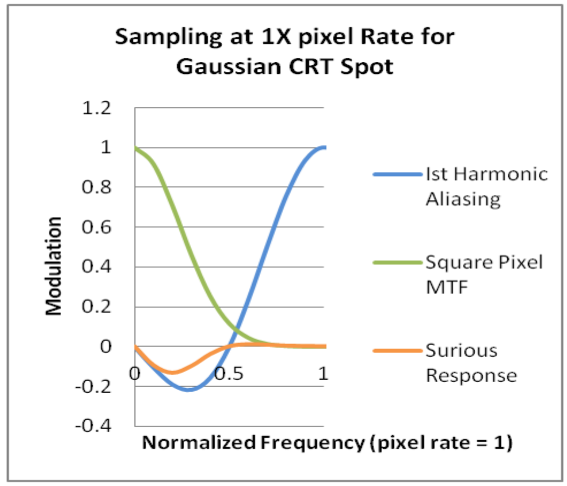

Figure 3 Sampling at 1X Pixel Rate for CRT Spot

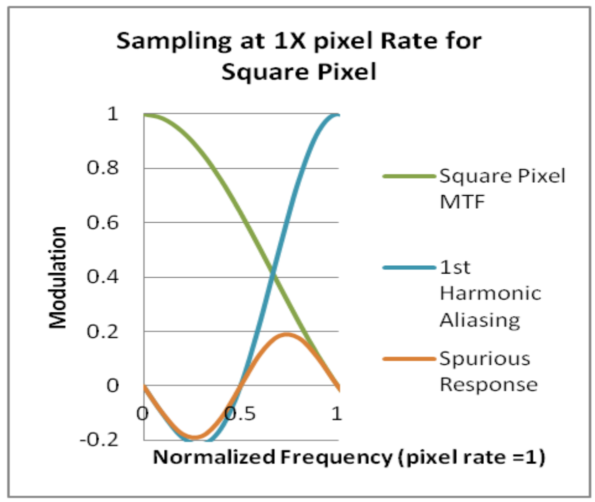

Figure 4 Sampling at 1X Pixel Rate for Square Pixel

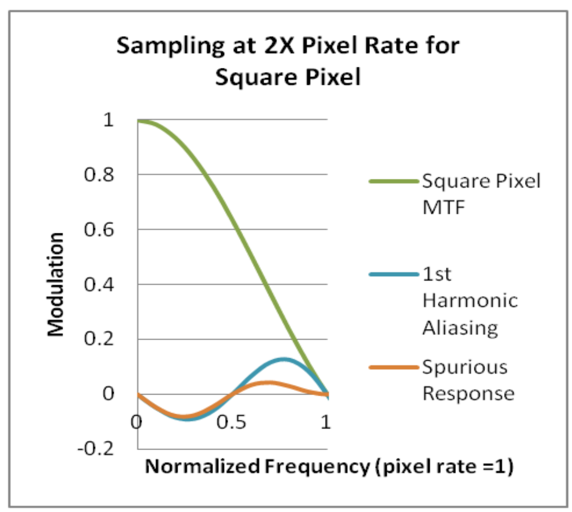

Figure 5 Sampling at 2X Pixel Rate for Square Pixel

Normally a factor of two increase in pixel rate in one direction would require a quadrupling of pixels, both in the projector and in the image generator. Not only would this result in a four-fold increase in cost, but the impact of four times as much hardware on system complexity might be unsustainable from a supportability standpoint.

IMPLEMENTATION OF DISPLAY SUPERSAMPLING IN A SINGLE PROJECTOR

JVC has developed a type of display supersampling that has become known as e-Shift. It uses an active optical device with no moving parts to translate the image precisely one-half pixel up/down, left/right on alternate frames, as shown in figure 6.

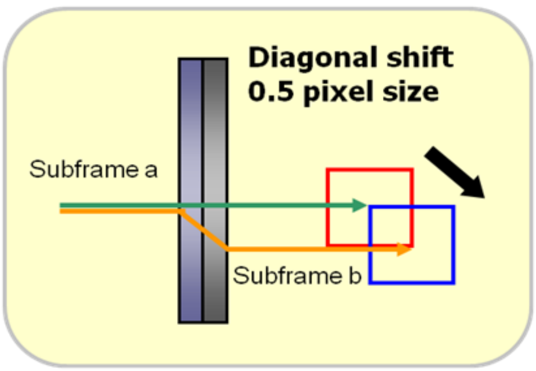

Figure 6 e-Shift Implementation

The image generation and display steps are unique and highly integrated in an e-Shift visual system as shown in figure 7. Note that the image data is sampled from an area that is smaller than the displayed pixel size and that pixels are overlapped.

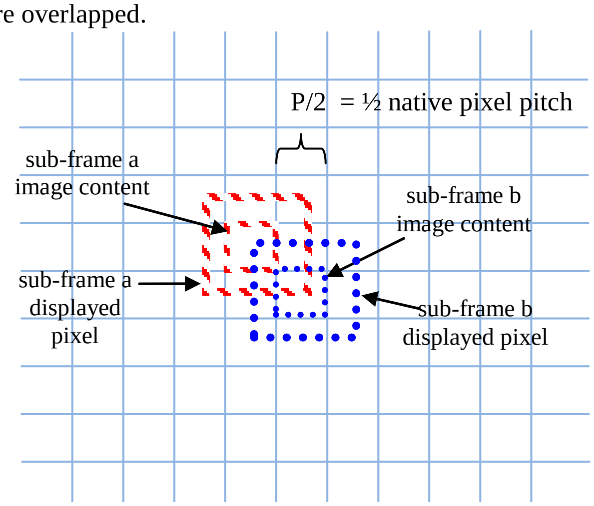

Figure 7 e-Shift Image Generation and Display

The MTF of an e-Shift projector can be thought of having two parts, a sampling effect and an aperture effect, as shown by Takahashi (2009). The sampling effect is calculated at the display supersample period P/2 by the formula in Equation 1.

Equation 1

$$f(x) = \frac{\sin\left(\pi \frac{P}{2} x\right)}{\pi \frac{P}{2} x}$$

This expression does not account for the overlap between pixels. The effect of the overlap is included in equation 2, where B is the effective overlap between a pixel and its neighbors. It is a function of the pixel pitch and pixel aperture.

Equation 2

$$f(x) = \frac{\sin\left(\pi \frac{P}{2} x\right)}{\pi \frac{P}{2} x} * \left(\frac{\sin(\pi(2B - P)x)}{\pi(2B - P)x}\right)$$

Since the effective pixel aperture is normally somewhat less than the pixel pitch, B is less than one and projectors with smaller pixel aperture ratios will have better e-Shift MTF. The theoretical MTF of an e-Shift projector, less lens and display screen, is plotted in figure 8 for various values of pixel overlap B. The figure also shows how e-Shift can extend the useable modulation well beyond the Nyquist limit of the native (non e-Shift) projector, even for pixel aperture ratios approaching 1. The pixel overlap can be thought of as a low pass filter which reduces aliasing in a way similar to the Gaussian spot filter on the CRT. As a result, image quality on an e-Shift display is comparable to a CRT display while resolution is many times better than the best CRT ever was.

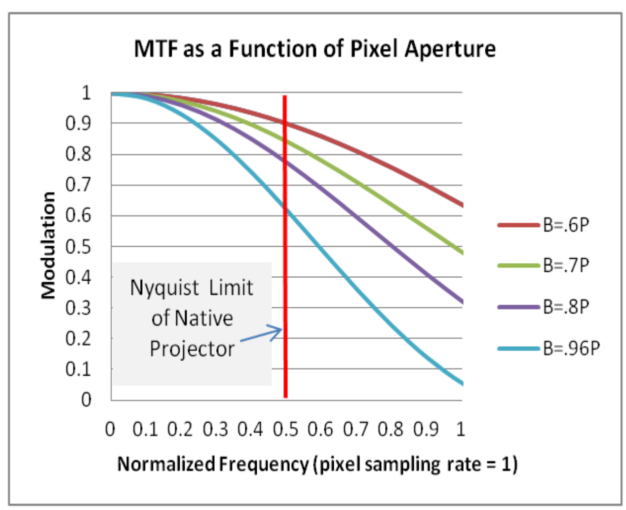

Figure 8

RESULTS OF E-SHIFT TESTING

A resolution test pattern was constructed using sixteen 1920 X 1080 HD test patterns repeated four times in each direction as shown in figure 9

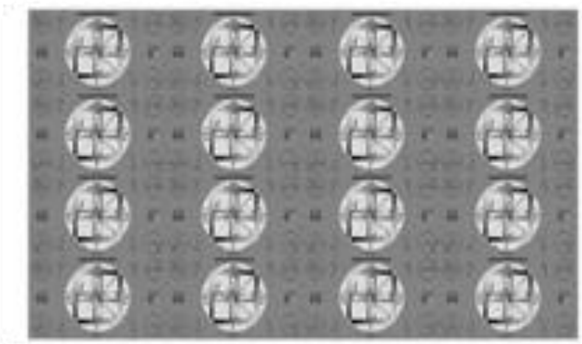

Figure 9 Resolution Test Pattern

Figure 10 is a photograph showing a close up of the image of figure 9 on an 8K E-shift projector.

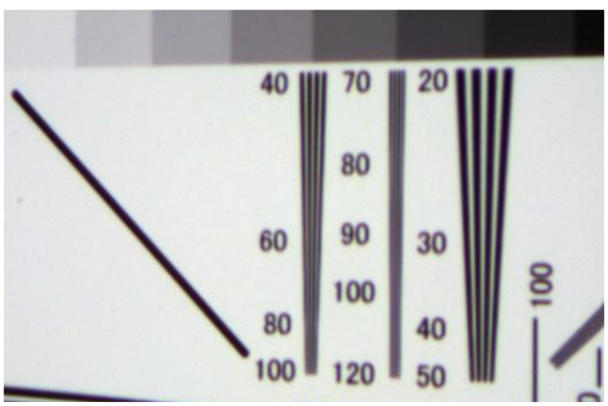

Figure 10 Limiting Resolution of e-Shift Projector

It documents the 850 lines per picture height that were visible to the eye at limiting resolution in each of the 16 resolution patterns shown in fig 6 for a total of 6040 X 3400 effective picture elements for the entire picture area, which has a native resolution of 4096 X 2160 pixels without E-shift.

CONCLUSION - BENEFITS TO THE WAR FIGHTER

The advantages of e-Shift technology for simulation and training are better resolution and higher image quality.
The e-Shift approach not only results in more "cycles on target" at realistic target range for real-world comparable DORI performance but it improves image quality by the nearly complete elimination of pixelization and aliasing effects. This improved performance can be achieved on an existing HD visual system without increasing the number of projectors or cost of consumables. The vision of a 20/20 immersive pilot display system, shown notionally in figure 9 from (Hoper 2005), has been brought much closer to reality thanks to a systems approach which leverages existing COTS devices with understanding of the human visual system

Figure 11 20/20 Immersive Pilot Visual System

ACKNOWLEDGEMENTS

Boeing and JVC acknowledge Rockwell Collins for their support in integrating the first real time interactive e-Shift display system.

REFERENCES

Damera-Venkata, N. & Chang, N. L. (2009). Display Supersampling. *ACM Trans. Graph. Vol 28, #1*, pages 9:1 to 9:19.

Devitt, Driggers, Volmerhausen et al. (2001). Target Recognition Performance as a Function of Sampling. *Proceedings of SPIE Vol. 4372*, pp 74 to 84.

Hopper, Darrel G. (2005). Technology Challenges for Military & Avionics Displays. *Proceedings of Society for Information Display ADEAC2005*, paper 3-1, pp 1 to 4

Johnson, J. (1958). Analysis of Image Forming Systems. *Proc. Image Intensifier Symposium*, pp. 249 - 273

Takahashi, Nomura, Sakai. (1999). Optical System and Characteristics of an LCD Projector with Interleaved pixels. *IEEE Transactions on Circuits and Systems for Video Technology, Vol. 5, No. 1*, pp. 41 to 47.