High Resolution Scalable Displays: Manufacturing and Use.

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Abstract

Tiling projectors provides an effective and easy option to increase screen space. Differences in projectors' components however contribute to non-uniformities in illumination and colour and detract from image quality and useability. In collaboration with JVC we developed a compact, high-resolution, uniform, tiled projection computer display based on a single common light source. A single set of red, green and blue dichroic filters provides the red, green and blue illuminations which are then guided by optical fibres to the projectors D-ILA (Direct Drive Image Light Amplifier) chips, JVC's projector technology. This results in a uniform illumination across the tiled projectors, a single colour temperature and a single colour balanced spectrum, with improved image uniformity. The display is driven by a graphics computer cluster running Linux and fitted with Nvidia graphics cards. We illustrate applications of this new display system with scientific applications in medical imaging and in radar imaging for archaeology.

Keywords: Computer display, high resolution, tiled projectors, D-ILA, optical fibre.

Introduction

Computer chips, data storage, networks are following Moore's law. It is now trivial to create large data files through computer simulations or with instruments. One of the challenges is to visualise such data sets. This increase has stimulated much development of scalable algorithms and software systems. A bottleneck for analysing large data and image files is at the display level. Computer displays whether cathode ray tubes (CRT) or liquid crystal displays (LCD) have remained stationary: few monitors or projectors are capable of displaying more than one million pixels or megapixel images (1280 x 1024 pixels) without downsizing the image. Tiling several projectors offers an easy solution to increase the display area and a way to achieve a seamless large image. Until recently expensive PowerWalls and Visionariums (Woodward et al. 1994, Van Dam et al. 2000) with 3-12 Mega-pixel capacity provided this solution. Today, systems based on commodity components and PCs, have started to appear in university labs (Raskar et al. 1999, Schikore et al., Funkhouser and Li 2000, Li et al, Hanrahan et al, Raskar, Hereld et al 2000, Yang et al., Pailthorpe et al. 2001). One problem inherent to tiling projected images is that, in general, uniformity of brightness and colour is not easy to achieve and may be impossible. This is due to factors such as manufacturing variability of projector components, including filters, lamps, optics, etc. This leads to differences in illumination and colours, and degrades the overall image quality. Even so, such systems require continual re-tuning and balancing due to differential ageing of the multiple projector lamps and other components. The tiled projection display system reported here solves many of these problems, resulting in superior performance.

1 Methodology

Two displays were fabricated in-house, one at the San Diego Supercomputer Center (UCSD) and one at the University of Sydney. The prototype is a 3 x 1 projector array, yielding a final image of 3840 x 1024 pixels with physical dimensions of 128 cm x 32 cm. The SDSC system was expanded to a 3x3 array. Both use D-ILA G1000 projectors from JVC, each with native resolution of 1350 x 1024 pixels (Sterling and Bleha 1997). The schematic diagram is presented on figure 1. A common source of illumination and a common set of RGB dichroic filters, are the key to a uniform illumination and colour across the tiles. The red, green and blue light are then guided via optical fibre to each D-ILA projector chip.

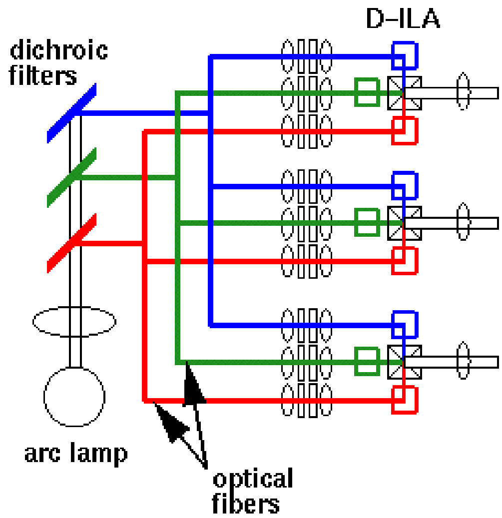

Figure 1: Schematic diagram of optical paths for the 3x1 tiled display.

1.1 Projector overhaul

Each projector was disassembled: the dichroic filters assembly, lamp housing and fans were removed and a new assembly built to bring the red, green and blue light via optical fibres to the projector's D-ILA chips. A 2,000 watt Xe arc lamp provides the illumination and three dichroic filters the common red, green and blue components. The red, green and blue beams are focused by a series of lenses and reflected down to the D-ILA chips by a mirror as shown in figure 2. The 2kW lamp was chosen for expedience, being readily available in the JVC product line and could drive satisfactorily a 20-projector tiled display system. A short throw (0.8:1) lens was fitted on each projector in order to achieve a 21" diagonal for each projected image tile, consistent with standard desktop monitors. Tests show that the diagonal can be reduced down to 15" without distortion thus increasing the pixel density from 75 dpi to 105 dpi. A Jenmar black glass screen was used in rear projection mode. Three projected images were tiled horizontally and the images were edge-abutted with pixel-level precision.

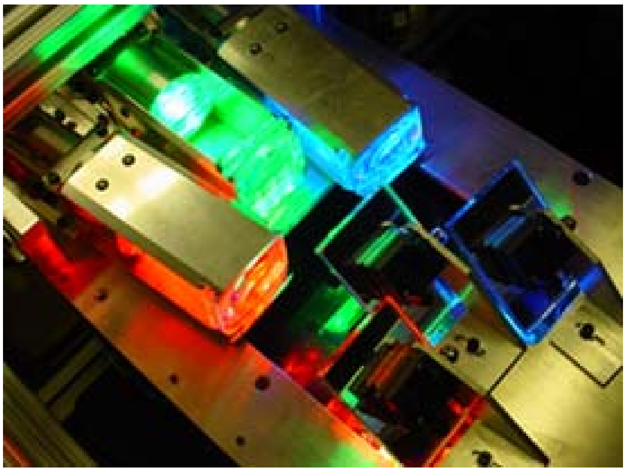

Figure 2: Light path on one projector: each light component is guided by optical fibre and reflected down onto the D-ILA chips by a mirror.

1.2 Alignment

In order to keep the integrity of the projected picture across the screen as tiled image components, the projectors are aligned precisely horizontally, and also vertically if several rows of projectors are present. The alignment was achieved using an in-house mechanical 6-axis positioner (Li 2000). Each projector opto-electronic core was placed on a positioner and each projected image was aligned physically using the three screws as shown on figure 3, at pixel level precision. Finer horizontal or vertical alignment is also possible within the projectors using the D-ILA proprietary control software which allows the user to directly control the brightness, contrast and sharpness of a picture, and to adjust in the projector circuitry the gamma curve of each D-ILA chip as well as the shading.

1.3 Edge Blending

Good image edge blending provides uniformity in illumination and chromaticity. Edge-blending software and hardware systems (Inova 1990, Mayer 1996) are commercially available, with increased cost and complexity. In both cases the edges of the projected images are "feathered" and allowed to overlap; they are then blended so that the final image appears seamless at the transition. The hardware approach involves a conversion from a digital signal to analog, the blending is done electronically. Many groups favour the software approach. It works well with CRT projectors however it is computationally intensive. Unfortunately LCD leak light at the edges due to reflections by the non-liquid crystal coated part of the silicon chip: this shows as a brighter area around the projected image and cannot be software-controlled. A simple solution is to abut the images precisely, as explained above, and to block the stray reflected light with a simple physical mask made of black cardboard (figure 4). When positioned close to the screen the edges of the mask are sharp and the transition appears seamless.

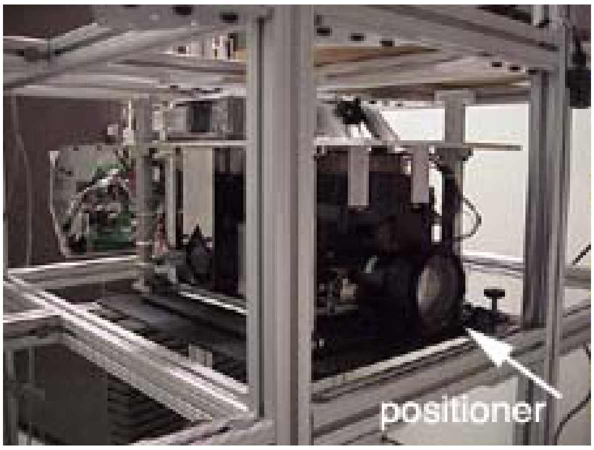

Figure 3: Front view of one of the tiled projectors, showing the 6-axis positioner in the mounting frame.

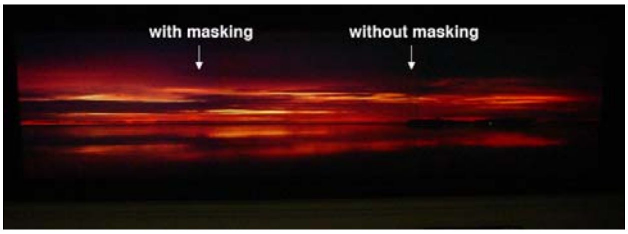

Figure 4: Seams with and without the masking.

1.4 Calibration

The three projectors were colour and luminance matched using a Photo Research PR-650 spectroradiometer positioned 30 cm away from the Jenmar screen. The projector with the less light output was used as the "reference". It was matched with the D65 illuminant (colour coordinates x= 0.313 and y=0.329) (Berns 2000). The two other projectors were then matched as closely as possible to that projector by tuning each D-ILA chip. The D65 coordinates were tracked from black to white by adjusting the projectors' gamma curves.

1.5 Computer system

A PC cluster (3 dual Pentium, 1GHz) running Linux was used to drive the 3-projector tiled display. A Matrox video card wrote to the three 1280x1024 projector and one monitor. This proved satisfactory for static images. Displaying animated 3D geometries is more problematic. We used WireGL / Chromium APIs (Humphreys and Hanrahan 1999, Hanrahan 2003) to render geometries across three Nvidia graphics cards. A more expensive alternative is to use an SGI Onyx2.

2 Results

2.1 Photometric characterisation of the display

Our new design solved problems of uniform illumination, and colour-matching across three projectors as shown by the photometry measurements presented on figure 5. The

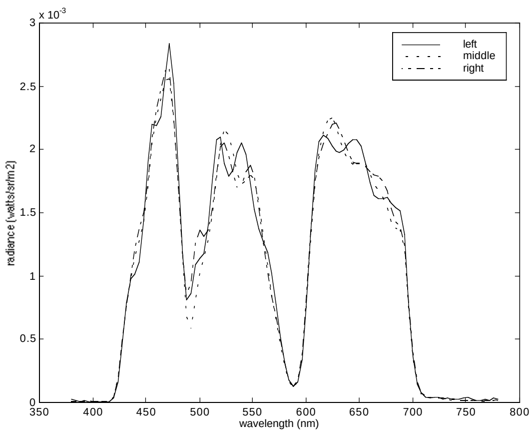

Figure 5: photometry measurements for the three projectors for white flat field.

measurements were done at the centre of each tile 30 cm from the screen. The difference in the spectrum envelope for each projector is probably due to manufacturing variability however this is not noticeable by the eye. The colour coordinates for white, red, green and blue are presented on figure 6 for the three projectors: the points are superimposed showing a good colour match. The colour remained uniform with time. However the colour coordinates for white seem to shift with time. The use of

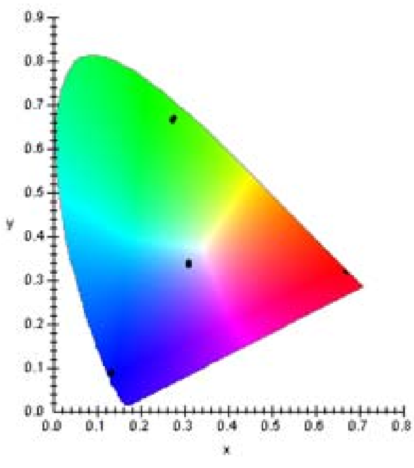

Figure 6: CIE coordinates of the tiled display.

a short throw lens increases the sensitivity to off-axis viewing at the image edges transition as shown in figure 7. Parallel rays striking the screen would eliminate this problem however the projectors would need to be mounted further away. Another solution would be to project the image on an angled mirror and reflect it back to the screen. Both solutions require more lab space.

Figure 7: Viewing angle sensitivity of the display.

The 3x1 desktop display is suited to images in the landscape format. These include satellite and GIS imagery and astronomical and medical images. The image representing the proposed Square Kilometre Array (SKA) telescope by Australia showcases the good levels of grey obtained on the display (figure 8).

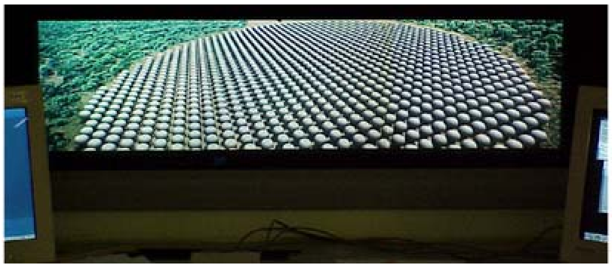

Figure 8: SKA telescope showing gray levels.

Photometric measurements were also performed on each image tile in a grid pattern to characterise the illumination uniformity. In general the luminance varies by 10-20%: this consistent with the expected fall-off from centre field.

Scalability from 3 x 1 array to a 3 x 3 array was demonstrated at UCSD in 2001 where we started this project in 2000 (Pailthorpe 2001). The San Diego display

Figure 9: 3 x 3 display at the University of California San Diego (courtesy of SDSC-UCSD).

is visibly less bright as it uses an acrylic screen. However the luminance levels are good enough to allow a person to work with the display. The seams on this display are now visible because Fresnel lenses have been used to parallelise the rays incoming on the screen. As a consequence each image tile has "shrunk". The solution is to realign each projector with the positioners.

2.2 Software Environment

As mentioned earlier a Linux cluster with Matrox and Nvidia video and graphics cards was used to drive the display. Existing software applications ran properly on the display. Displaying images with shareware software such as xv was quite easy. Displaying geometries is more complicated. We used Chromium, the successor to WireGl to use OpenGL-based applications to run across several graphics cards. A program was developed to facilitate the configuration of Chromium (McMillan 2003). Figure 10 shows the SGI Performer town running on our display. More applications are shown in the next section.

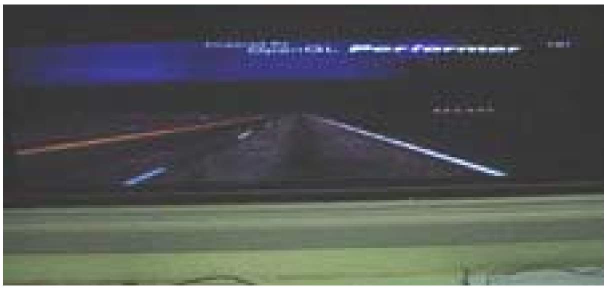

Figure 10: SGI performer town on the display.

3 Applications

The performance and utility of the new computer display is illustrated by two applications in scientific visualisation, taken from our laboratories. Two examples are presented below.

3.1 Application to Medical Imaging

The performance and utility of the new computer display is illustrated by an application in scientific visualisation, involving medical imaging of CT scans. The reconstructed 3D abdomen is shown in figure 11. The 3D model was built using OpenDX and Chromium to lace the image tiles together.

Figure 11: Medical imagery displayed using OpenDX.

3.2 Application to Archaeology

Angkor lies to the north of Siam Reap in Cambodia and houses one of the world's largest religious monuments (Coedes 1963, World Monuments Fund 1995) with spectacular stone temples. In its heyday, between 800 and 1400 AD, Angkor was the capital of the Khmer Empire. The city was abandoned gradually and the seat of power transferred to Phnom Pen, the current capital of Cambodia. The jungle reclaimed the old city. Angkor came to the attention of the Western world when Henri Mouhot, a French explorer, re-discovered it in 1860. The restoration plans started at the beginning of the 20th century were interrupted by the civil war of l970-1975 and during the Khmer regime. The area lying north of Angkor is heavily mined and examination of the site is dangerous. In 1994 the site of Angkor was included in the target list for the Spaceborne Imaging Radar (SIR)-C/X-Synthetic Aperture Radar (SAR) mission at the request of the World Monument Fund and the Royal Angkor Foundation. The mission was a success with the discovery of new temples and archaeological sites. New Airborne SAR missions were flown subsequently. We present here some recent Airborne Synthetic Aperture Radar (AIRSAR) data of the Angkor area.

AIRSAR (JPL 2001) was designed and built by the Jet Propulsion Laboratory. It uses three wavelengths: L-band (23 cm), C-band (5 cm) and P-band (65cm) carried in a modified NASA DC-8 aircraft. It can be used in two modes: straight imaging or interferometry (for topographic height data measurements). The longer wavelengths can penetrate through the overlying dense forest canopy and, in extremely dry areas, through thin sand cover. This sort of imaging reveals ancient canals, roads and stonework. Judicious combination, filtering and manipulation of the radar images can sharpen features and reveal historical settlements and agricultural fields, which previously were unknown from ground surveys. Two false-colour radar images of Angkor are shown in figures 12 a and b. The ability to display four megapixels

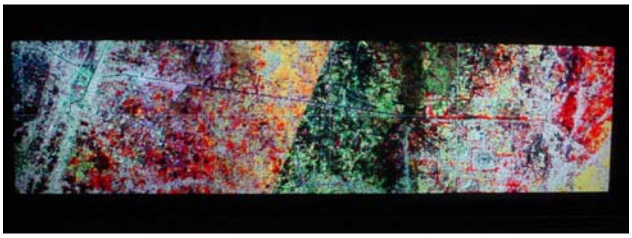

Figure 12a: AIRSAR image of the central area Angkor, displayed on the black screen.

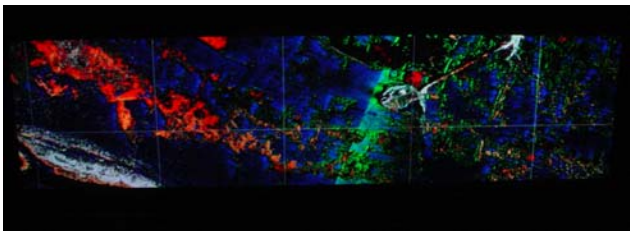

Figure 12b: AIRSAR image of the great lake south of Angkor.

at one time has been valuable to archaeologists who are looking for future archaeological sites. The radar showed details within the perspective of the rest of the image. Such approaches augment traditional research methodologies in archaeology and will guide future fieldwork and excavations.

3.3 User Interaction

We realised quickly that regular interaction devices such as a mouse are not adequate for a tiled display: moving a mouse over 4,000 pixels to reach the right-most projector takes several iterations. As a consequence users tend to use the left and middle projectors. We are currently assessing different user interaction devices including a tablet and stylus and joysticks. So far the response has been positive: instead of overlaying several windows, the users tend to "spread" over the display space just as they do with a larger office desk. Clearly an evaluation of the display by human factors researchers is necessary.

4 Concluding Remarks

Using a common light source and a set of dichroic filters to illuminate the D-ILA projector chips is an effective solution for creating a seamless tiled display. This design is a significant improvement over low cost systems; in displayed image quality, compactness, and price; and thus allows improved scalability, pointing the way to higher capacity displays in the near future. However this solution cannot be applied to inexpensive projectors using a colour wheel to provide the red, green, blue lights.

The initial colour and illumination matching process is slow and time consuming but need only be done once. Tiled projection displays entail significant fabrication, maintenance effort and costs. Our common light source design results in a relatively fragile system; the system could be hardened with further development effort. However many laboratories over the world are building tiled projector displays (Wilhelmson et al 2002). NCSA for instance assembled a 32 megapixel array by tiling 40 projectors (8x5 image tiles) indicating practical scalability of the design (NCSA 2002). Research on the useability of such displays needs to be done to estimate how much can the human brain work with.

The display industry is also making progress. IBM’s 200 pixel per inch, 8.5 megapixel LCD panel is commercially available. LG-Phillips has announced a 265 ppi QUXGA LCD display (Kim 2002), destined for laptop usage. Driven by the commercial ramifications of digital cinema new generation projectors with tighter manufacturing tolerances are becoming available as exemplified by JVC QXGA (2k x 1.5k pixels) D-ILA projector and a QUXGA (4kx2k) D-ILA prototype. Finally new developments based on organic semiconductor technology such as Organic Light Emitting Diode (OLED) devices are paving the way to new types of displays.

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References

Berns, R. S. “Principles of Colour Technology”, John Wiley and Sons, 2000.

Coedes, G. “Angkor – an Introduction” (trs and ed. E F Gardiner), Oxford University Press, 1963.

Funkhouser, T., Li, K. (2000): Large-Format Displays, *IEEE Computer Graphics and Applications*, **20(4)**, 20.

Hanrahan, P. et al., http://www-graphics.stanford.edu/projects/multigraphics/ and ; http://graphics.stanford.EDU/software/wiregl/. Accessed 6 October 2003.

Hereld, M., Judson, I., Stevens, R. (2000) Tutorial: Introduction to Building Projection-based Tiled Display Systems, *IEEE Computer Graphics and Applications*, **20(4)**, 22.

Humphreys, G., Hanrahan, P. (1999): A Distributed Graphics System for Tiled Displays, Proceedings of *IEEE Visualization Proceedings*, San Francisco, CA, 215.

Inova, P. "*Seamless video display*", US patent # 4,974,073, issued 27 Nov. 1990.

JPL: AIRSAR (2001) http://airsar.jpl.nasa.gov/ Accessed 6 October 2003.

Kim, H. (Oct 17, 2002): PC Monitors: beyond 200 ppi; http://www.usdc.org. Accessed 6 October 2003.

Li K. et al., http://www.cs.princeton.edu/omnimedia/, Accessed 6 October 2003.

Li, K. (2000) Positioner originally suggested by Kai Li, Princeton, and modified by UCSD and University of Sydney; designs archived at: http://www-fp.mcs.anl.gov/fl/research/index.htm. Accessed 6 October 2003.

Mayer, T., (1996): Design considerations and applications for innovative display options using projector arrays, *SPIE proceedings*, vol. **2650**: projection displays II, M.H. Wu, ed., SPIE, Bellingham, Washington, 131-9.

McMillan S. et al http://www.vislab.usyd.edu.au/research/display_soft/index.html. Accessed 6 October 2003.

NCSA (2002) http://www.ncsa.edu/; and reported in http://ams.confex.com/ams/annual2002/techprogram/paper_29123.htm, Accessed 6 October 2003.

Pailthorpe, B., Bordes, N., Bleha, W. P., Reinsch, S., Moreland, J. (2001) High-Resolution Display with Uniform Illumination, *Proceedings of Asia Display - IDW'01*, Nagoya, 1295.

Raskar, P., Brown, M., Yang, R., Chen, W., Welch, G., Towles, H., Seales, B., Fuchs, H. (1999) Multi-Projector Displays using Camera-Based Registration, *Proceedings of IEEE Visualization*, San Francisco, CA, 161.

Raskar, R., (2000): Immersive Planar Display using Roughly Aligned Projectors, *IEEE VR 2000 Proceedings*, New Brunswick, NJ, 109.

Schikore, D. R., Fischer, R.A., Frank, R., Gaunt, R., Hobson, J., Whitlock, B., (2000): High-Resolution Multiprojector Display Walls, *IEEE Computer Graphics and Applications*, **20(4)**, 38.

Sterling, R., Bleha, W. P. (1997): ILA projectors for advanced imaging applications, *Proc. Society for Information Display Workshop*, USA, 809.

Van Dam A, Forsberg, A. S., Laidlaw D. H., LaViola, Jr, J. J., Simpson, R. M. (2000): Immersive VR for Scientific Visualization: A Progress Report, *IEEE Computer Graphics and Applications*, **20(6)**, 26.

Wilhelmson, R., Baker, P., Stein, R., Heiland, R.(2002): Large Tiled Display Walls and Applications in Meteorology, Oceanography, and Hydrology *Proceedings 18th Int. Conference on Interactive Information and Processing Systems (IIPS),* 29-30.

Woodward, P. et al., http://www.lcse.umn.edu/research/powerwall/powerwall.html. Accessed 6 October 2003.

World Monuments Fund, (March 1995): Radar Imaging survey of the Angkor Eco-Site, report of the first scientific roundtable. Royal Angkor Foundation, New York.

Yang, R., Gotz, D., Hensley, J., Towles, H., Brown, M. (2001) PixelFlex: A Reconfigurable Multi-Projector Display System, Proceedings of IEEE Visualization, San Diego, CA, 21.