Realizing Perceptive Virtual Reality Imaging Applications on Conventional PC Hardware

Toby P. Breckon, Karl W. Jenkins, and Pal Sonkoly

***Abstract*— In this work we investigate the immersive presentation of 3D content using real-time multi-view projection from a conventional PC hardware platform. By combining the available graphics capability of a modern workstation with an established, low-cost technique for multi-view image separation we present a technique for real-time, interactive virtual reality content presentation. We present a number of potential imaging applications with exemplar results the medical, engineering, geo-spatial and educational domains.**

***Index Terms*— virtual reality, 3D image projection, GPU.**

I. Introduction

Numerous contemporary techniques now exist for the display of 3D content in an immersive context commonly denoted as "Virtual Reality" - essentially the projective display of 3D information such that is is perceived as having depth within the viewers field of view as opposed to just the 2D projection of a 3D entity on a 2D display screen [1]. Despite this, both commercial offerings and current research systems in this domain are characterized by significant installation and maintenance costs that limit their use to specialist research and development organizations or specific entertainment-focused installations. This limitation largely places Virtual Reality (VR) visualization technologies out of the reach of many potential users. However, the core concept of VR presentation remains in essence, very simple – the presentation of discrete visual fields to the left and right eye of the human viewer such that the advanced stereoscopic reasoning of the human visual system will reconstruct the perception of a 3D object from what is essentially two 2D discrete views of the same [2].

Here we re-investigate the use of an established method in this domain, anaglyph stereo [3], in conjunction with the redundancy in the real-time graphical rendering capability of modern PC graphics hardware (as of 2008) for the real-time interactive presentation of VR content from a conventional PC platform. We show that this previously static view separation technique can now be realized for for real-time interactive use on contemporary PC hardware,

II. Multi-view 3D Image Presentation

The perception of the VR experience essentially relies upon the 3D perception of the 3D content held on the generating computer system. The storage and display of 3D content as a projection on to the 2D image plane (display screen) is a conventional function of 3D graphical display on a PC. By contrast the presentation of multiple discrete 3D views to a single viewpoint via a single 2D image plane is not so.

All VR technologies essentially operate via the presentation of multiple discrete views to the viewer [1]. These views are separated in geometric viewpoint such as give the two discrete view of a given object (Figure 1).

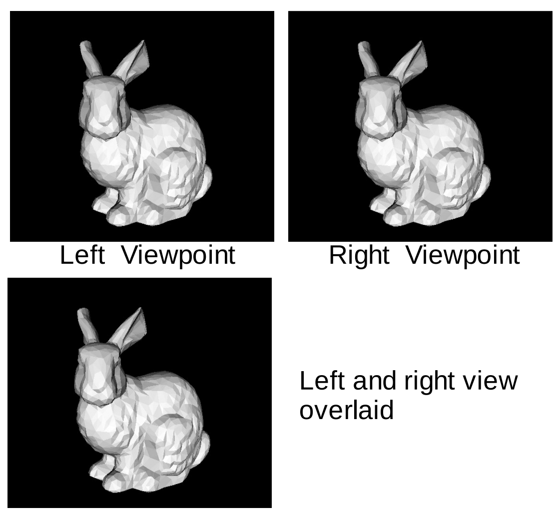

Figure 1: left and right viewpoints of example 3D content

As shown in Figure 1 the differences in the viewpoints are commonly encoded as left and right object views along a relatively short base-line. Indeed, as the examples in Figure 1 (upper) show, the required difference in viewpoint is minimal and often unapparent when the left/right image views are

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rendered separately. Overlaying the left and right views (Figure 1, lower) show the the subtle differences in the form of detail blurring in the resulting image overlay.

VR systems essentially make use of projective stereo to present multiple views of a given object (or scene) to the viewer. VR creates these two virtual views of the object and then, by presenting them to the viewer, relies on the human visual system to reconstruct the perception of an immersive 3D view in exactly the same way it operates for conventional scene viewing from the left and right eyes. Conventionally, on traditional VR systems, each view may be generated via a separate graphics pipeline and possibly be projected from a different source onto the image plane (projection screen). Each view must be separated in some manner such that the information in each can be detected discretely by the human visual system. As shown in Figure 1 (lower) the presentation of both views in a combined, mixed in-differentiable signal will not facilitate the stereoscopic realization the intended 3D perception. The method of view separation is the key functional discriminator between the majority of VR imaging technologies.

VR is essentially presented to the viewer as two separate 2D views, separated using either a spatial or temporal methodology, which the human visual system then forms into the perceived 3D scene or object. *The notion that VR uses 3D projection is a myth* – VR uses 2D projection (x2) which is then perceived as a 3D projection. Two separate views of the same scene are presented to the viewer either simultaneously or near simultaneously to achieve the overall perception of 3D content as intended.

Several VR systems use temporal separation to present each of the 2D views [4]. By presenting each differing view point in rapid sequential succession the human visual system interpolates the notion of a 3D scene in a similar manner to the visual interpolation of the moving image when viewing a rapid succession of still images as a film or television broadcast. Presentation of 3D content in this way echos sequential "flick-book" presentation of stereo image pairs from early film-based stereo cameras (dating back to mid-1850s or earlier). In modern VR systems the differing views of the 3D content are presented in rapid succession at ~25-50Hz (or greater) to essentially create the same effect. Although relatively effective, artifacts of this temporal "shuttering" process have limited its general uptake.

The most common method of multi view presentation utilized in VR systems is spatial separation [4]. The multi views are separated spatially such that either portions of each are presented to each eye or separate views are presented via complete spatial view separation. Again the presentation of multi view imagery in this way dates back to the early "side -by-side" stereo image viewers of the 1850s and earlier. More recently the use of spatial multi view separation was commonplace in the 3D movies of the 1960s (to present day) where we see the use of spectral filtering in the form of red/green anaglyph stereo in common use. Many commercial offerings in VR today utilize the same paradigm of view separation through the use of the common concept of "VR glasses" or more complex "VR headsets". These devices essentially control the view provided to the viewers left and right eye such that, though the use of spatial view separation, each may be varied independently to achieve the desired 3D effect. Commonly, approaches based on headsets rely on separate image presentation (e.g. left and right image versions, Figure 1) whilst the more compact hardware use of glasses implies an approach based on either synchronized or un-synchronized temporal/spatial shuttering between multi view images presented on a common projection display. In such a approaches the actual projected image is actively or passively interlaced between the two views (e.g. Figure 2) with the corresponding VR glasses providing the spatial separation of the two views – one for each eye.

Recent interpretations of this technology have seen the concept of spatial separation move from the human viewer (i.e. glasses/headset) to the projection screen itself – both recent 3D display products from Philips [5] and Sharp (Actius RD3D laptop) utilize variations on lenticular lens technology that was first used for static 3D image display in the 1940s [6].

Majority of current VR research work is applications or interactive enhancement based [7] with only limited investigation of enhanced view projection and presentation techniques [8]. In the majority of cases work in these latter areas is driven primarily by hardware innovation that offers improved presentation quality (e.g. resolution/colour perception), consumer level production costs and/or miniaturization. The fact that the required two (or more) views can only be presented via either spatial or temporal separation to the human visual interface (two 2D receptors = eyes) is a governing paradigm of all projection approaches in VR.

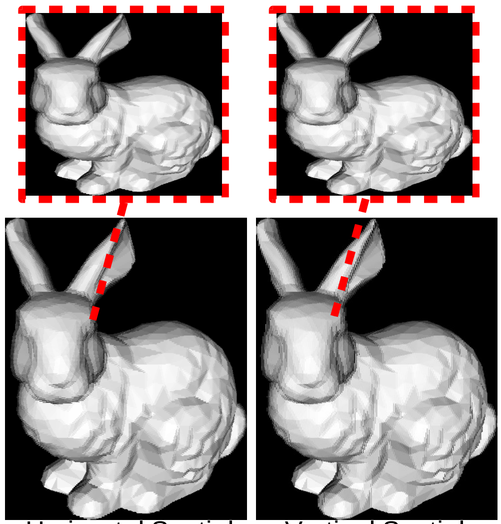

Figure 2: Spatial view separation via horizontal/vertical view interlacing

A. Limitations of Current Multi-view Options

Most of the available multi-view presentation options have inherent limitations. Temporal separation commonly introduces perceptive artifacts into the resulting 3D content presentation whilst spatial separation techniques suffer from both technological and perceptive limitations. The use of active headsets in spatial separation techniques are prohibitively expensive for widespread adoption and have an associated maintenance and notably user encumberment factors. VR solutions based on active/passive glasses are less so in all areas but cause certain levels of distortion in the displayed image (e.g. Figure 2 / Figure 3). This spatial distortion prevent effective simultaneous viewing of the display by both VR participants and non-participants (i.e. dual VR 3D and conventional 2D viewing).

As can been seen from Figures 2 and 3 the spatial separation of the views by either view interlacing (Fig. 2) or the use of separate spectral colour filters per view (Fig. 3) interferes with the regular perception of the presented imagery to differing degrees. In the case of spatial separation via interlacing (Figure 2) an additional constraint is also placed on the VR user to maintain a near vertical or horizontal head position relative to the projected display in order not to lose the perception of the 3D scene content. This requirement limits the effective use of these techniques away from the user interactive domain such as physically interactive VR games or training scenarios (e.g. playing golf in VR).

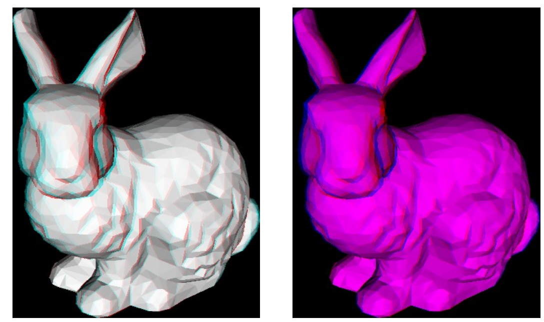

Figure 3: Spatial view separation via differing spectral colour filtering

From the examples shown the anaglyph stereo projection approach (Figure 3, right) is notable for the absence of such obvious visual interference although its presence is mildly apparent and is noted in earlier studies [9].

B. Anaglyph Stereoscopic Display

Due to the prohibitive cost of many VR technologies the presentation of 3D information to the mass (i.e. public Internet) audience is following somewhat of a renaissance in the older style multi view presentation techniques. The public dissemination of the stereo imagery from the recent NASA robotic missions to Mars has utilized anaglyph stereo as a low-cost method of presenting static 3D information to a wide audience in a standardized way [10]. The ready availability of the only required hardware elements, a standard PC and a set of low-cost red/green glasses (Figure 4), makes 3D information dissemination in this way highly inclusive across all levels of the industrial, research and education sectors .

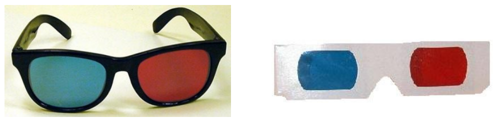

Figure 4: Low-cost anaglyph "red/green" stereo glasses

Conceptually anaglyph stereo image production is a simple technique that involves the semi-transparent compositing of the required left and right image views at a given horizontal disparity [3]. In computer graphics terminology we essentially alpha-blend (transparent object co-rendering) the images as if they were surfaces with each under a different ambient lighting condition (left – red, right -green).

This analogy with operations commonly performed in a computer graphics rendering pipeline means that the required compositing of two scene views for anaglyph viewing can be performed highly efficiently on modern graphics (i.e. GPU) hardware.

III. 3D Presentation on Modern PC Graphics Hardware

With the capabilities of the graphics hardware in a modern PC under consideration we turn our attention to the required operations to render 3D scene content to a anaglyph stereo representation.

As we can see from the example of Figure 1, the rendering of 3D content as an anaglyph stereo image essentially requires the generation of multi scene views (left and right) following by the rendering of both as an alpha-blended (transparent muli-layer) red/green image. The required left/right colourings can be simply added by using different global ambient lighting conditions in the graphics pipeline operations for each view point. The generation of multiple scene views of even reasonably complex 3D scene views is now easily within the real-time capability of even a modest Graphics Processor Unit (GPU) available in the consumer PC market [12]. The alpha-blend compositing and variable ambient rendering is similarly readily achievable within real-time bounds on contemporary GPU capacity [12].

From this analysis of both the requirements for the generation of anaglyph stereo as a method of spatial VR view separation and the capability of current GPU technology we outline the implementation and subsequent results of real-time, interactive (dynamic) VR content projection from standard single PC hardware.

IV. Implementation

The required graphics rendering is implemented using the OpenGL graphics pipeline API using a graphics abstraction library (VTK) in C++ under the Linux operating system. This allows the use of specific anaglyph GPU hardware and/or driver support where available, hardware OpenGL rendering where available and a fall back to software rendering under non-ideal (hardware limited) conditions depending on the specification of the host system. The availability of OpenGL hardware rendering or hardware anagylph rendering significantly improves performance.

The implementation operates with real-time performance on minimum specification graphics hardware (e.g. Nvidia GeForce 2 or similar) and provides significantly advanced performance, in terms of complex geometry rendering, on contemporary graphics hardware (e.g. Nvidia GeForce 7400 or better).

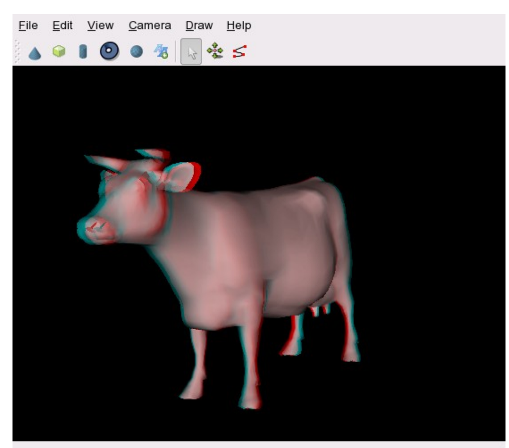

Figure 5: Implementation of VR rendering via anaglyph spatial view separation within a 3D viewer application.

A. Additional Implementation Features

As part of a usability evaluation study the graphics rendering implementation was embedded into enhanced 3D data viewer application (Figure 5).

This facilitates common data format compatibility with a range of 3D standards in addition to various additional visualization enhancements such as transparent surface rendering, defining camera flight paths and surface property editing.

V. Results

From our investigation of this VR visualization technique over a range of examples we present the following results.

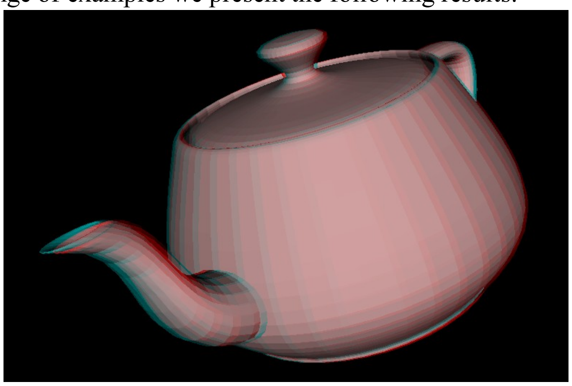

Figure 6: 3D projective visualization of traditional "Utah" teapot surface model

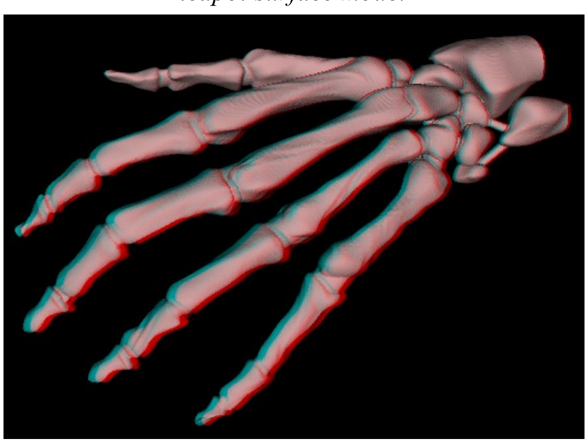

Figure 7: 3D projective visualization of the skeletal structure of the human hand.

Figure 5 – 13 show different 3D content presented using the proposed projective VR visualization technique. The examples shown can be viewed in projective 3D using the appropriate red(left)/green(right) anaglyph glasses (Figure 4) and display as an interactive VR style projection on conventional PC hardware using the implementation detailed. Figures 6 and 7 show the projective display of the traditional computer graphics teapot test object and the visualization of the skeletal structure from a human hand using this approach.

Figure 8 shows both the projective VR visualization and the regular PC-based 3D rendering of a surface type common to industrial visual inspection tasks [14]. In Figure 9 we see the proposed approach applied to the VR visualization of a surface with complex surface relief akin to that used in surface completion work of [15].

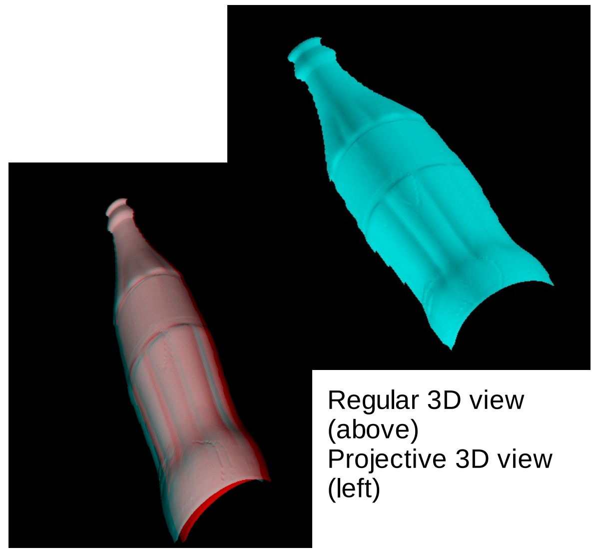

Figure 8: 3D projective visualization contrasted against regular 3D viewing for industrial surface inspection

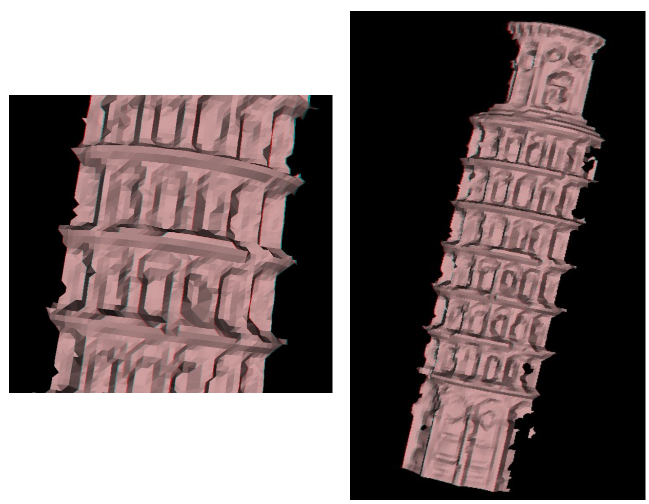

Figure 9: 3D projective visualization of complex surface relief

In Figure 9 we additionally show the technique successfully applied to the visualization of complex surface relief as utilized in the 3D surface completion work of [15].

This approach has many applications in the low-cost visualization of 3D data originating from a range of different domains. In Figure 10 we see the successful visualization of data originating from the geo-spatial domain whilst in Figure 11 we see the visualization of iso-surfaces extracted from a dense CT scan of a human head. Empirically variation in viewer head angle does not appear to degrade the overall quality of the 3D visualization significantly (e.g. ~45 deg.).

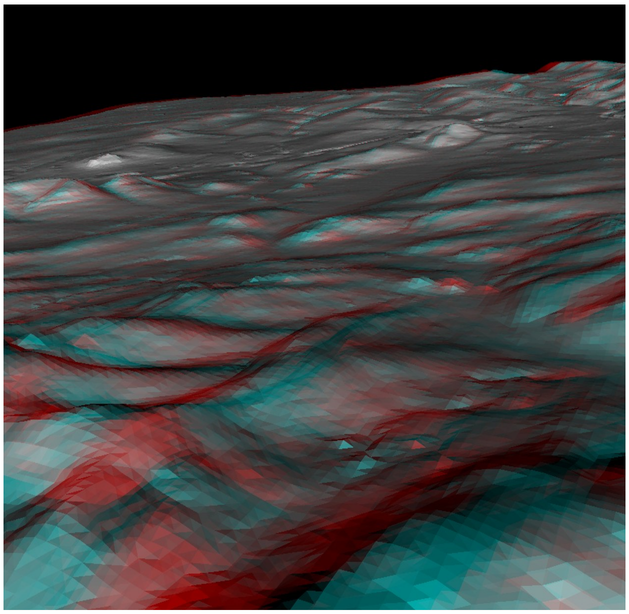

Figure 10: 3D projective visualization of geo-spatial terrain

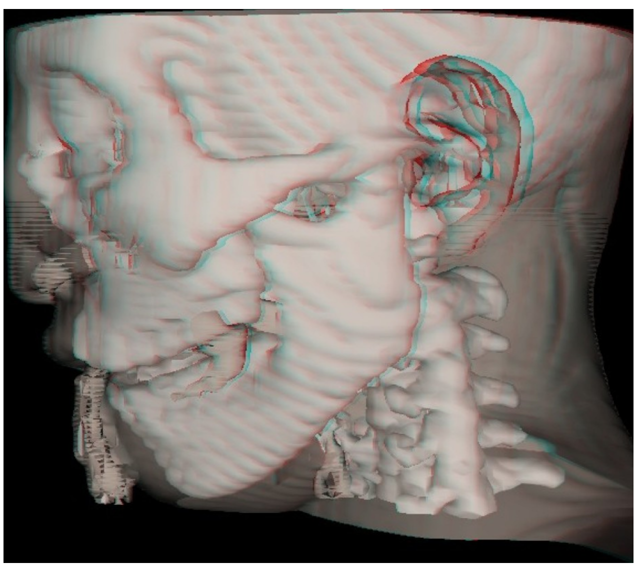

Figure 11: 3D projective visualization of iso-surfaces extracted from CT scan of human head.

Figure 11 also shows the combined use of in scene alpha-blending to provide transparent rendering of the human skull through the outer skin iso-surface in combination with the use of the anaglyph based VR projective technique. Despite the added complexity of this rendering operation real-time, interactive performance is maintained.

Figure 12 (left) shows the display of an example colour surface using the proposed approach together with an application in investigative CFD visualization [16]. We see colour perception is apparent although mildly degraded under the anaglyph projection.

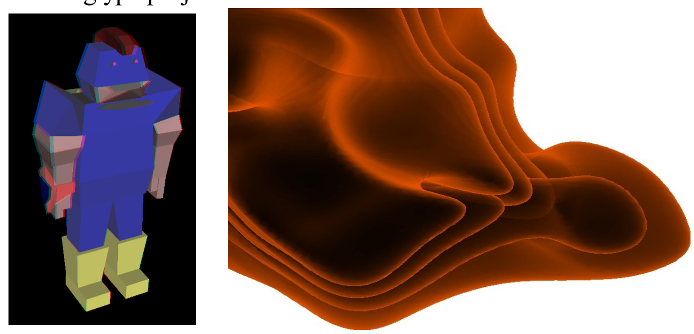

Figure 12: 3D projective visualization of colour and CFD surfaces

VI. Conclusions and Future Work

We present a low-cost technique for effective interactive VR content presentation via the application of the established technique of anaglyph multi view separation to real-time 3D graphics display. Colour perception is mildly degraded in the resulting presentation [13] and an overhead in the graphics rendering pipeline apparent for highly complex geometries. R Future work will investigate these limitations within the processing abilities of modern GPU hardware.

Full colour examples/videos of the work presented in this paper together with examples of real-time VR interactive display are available from the following URL: http://www.cranfield.ac.uk/~toby.breckon/demos/vr/

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