UKAEA-CCFE-CP(18)10

S. A. Silburn, G. F. Matthews, T. W. Morgan, R. E. Nygren, the Magnum PSI Team

Development of webcam-based near-infrared thermography in support of high temperature heat pipe experiments on Magnum PSI

Development of webcam-based near-infrared thermography in support of high temperature heat pipe experiments on Magnum PSI

S. A. Silburn, G. F. Matthews, T. W. Morgan, R. E. Nygren, the Magnum PSI Team

This paper has been submitted to
45th European Physical Society Conference on Plasma Physics (EPS), Prague, 2-6 July 2018

CCFE
CULHAM CENTRE FOR FUSION ENERGY

UK Atomic Energy Authority

UKAEA-CCFE-CP(18)10

Ronan Kelly, Guy Burroughes, Robert Skilton,
Jonathan Naish

Real-time volumetric rendering of radiation fields using 3D textures

Real-time volumetric rendering of radiation fields using 3D textures

Ronan Kelly, Guy Burroughes, Robert Skilton, Jonathan Naish

This paper has been submitted to
30th Symposium on Fusion Technology (SOFT), Giardini Naxos, Messina, Sicily, 16-21 September 2018

Real-time volumetric rendering of radiation fields using 3D textures

Ronan Kelly[a], Robert Skilton[a], Jonathan Naish[b]

[a] *RACE, UKAEA, Culham Science Centre, Abingdon, OX14 3DB, United Kingdom*
[b] *CCFE, UKAEA, Culham Science Centre, Abingdon, OX14 3DB, United Kingdom*

Abstract

The remote maintenance of nuclear fusion facilities must be carefully planned and monitored due to the potential damage to equipment caused by ionising radiation resulting from neutron activation. We present a method for visualising three-dimensional radiation dose fields in real-time. An interactive volumetric representation is achieved using view-dependent parallel ray casting of a scalar field in three dimensions.

Keywords: Dose map, Data visualisation, JET, Virtual reality

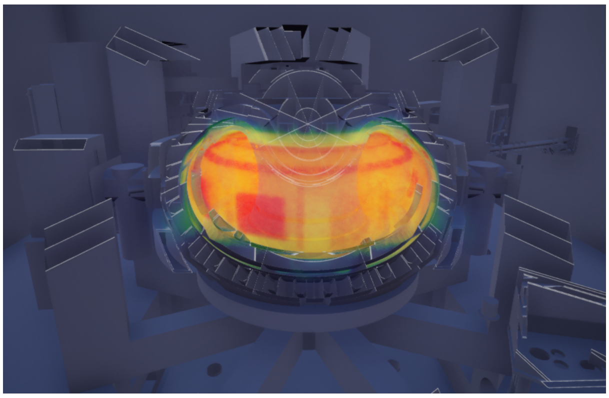
1. Introduction

Remote handling technology is used for repairing components in tokamaks that have been damaged or activated by energy produced by nuclear fusion reactions[1]. Simulation software such as the Monte-Carlo N-Particle Transport Code[2] (MCNP) is used regularly for planning such activities [3]. Engineers use the results to forecast and therefore minimise radiation doses to material, equipment and personnel involved in operation and maintenance of fusion devices such as the Joint European Torus (JET)[4]. We expect this process to become operations-critical for future high-yield fusion facilities such as ITER and DEMO.

Visualising the results of such simulations is essential for operations engineers to develop remote handling tasks that minimise the dose to equipment. A typical output of the simulation process is a cell-based data format such as Visual ToolKit (VTK) which can be used for offline expert analysis or plotting. The results are tightly related to the CAD geometry used in the simulation, and hence are often visualised as an overlay[5].

In this contribution a new method for the real-time visualisation of simulation results as a dense volume is presented. Although sample data stored as ASCII VTK has been used for this paper, the software architecture is generic to allow future extension to other file formats.

Figure 1: Our method - a dose volume visualised with a cutaway model of the JET vessel.



We achieve interactive real-time performance by exploiting parallel processing on the graphics processing unit (GPU), with scalar field data uploaded as three-dimensional (3D) textures. Lack of consumer hardware support for true 3D texturing is mitigated with software indexing of two-dimensional textures containing multiple XY slices through the volume. Integration with a commercial-off-the-shelf open source software framework, Unreal Engine 4 (UE4), allows fusing with context geometry derived from computer-aided design (CAD) engineering models and viewing with virtual reality headsets to support remote handling task development.

Readers should note that all figures are purely for illustration, and source data has not been verified or approved for use in any engineering assessments.

2. Radiation dose maps

Remote handling operations engineers at facilities such as JET plan operations in a process known as task development, using real-time simulations of remote handling equipment such as VR4Robots to check for collisions and develop optimal sequences [6]. Simulation results are typically presented to remote handling operations engineers for use in task development as dose maps in a static plot (see Figure 2). Even when this plot is 3D, it is difficult and error-prone to reconcile with a remote handling simulation which may contain different context geometry, unit scale and colour coding. This motivates the development of our method, which allows full integration with remote handling simulations in UE4 (see Figure 1).

Previous work by the UK Atomic Energy Authority developed the VORTEX software package [7] for representing radiation as a 3D overlay of contours onto CAD geometry for use with VR headsets. VORTEX is optimised for tracing the dose received by human operators in a volume, whereas our method is focused on expert visual assessment of the dose to remote handling equipment. Rather than showing only isosurfaces to show the contour of dose fields, we have developed a way to simulate a dense volume of varying density analogous to a cloud of water vapour. Similar functionality is available in the open-source scientific data visualisation tool ParaView [8], but is not suited for integration into existing remote handling simulation tools.

3. Raymarching volumetric data

Our method introduces a ray-casting step into the rasterisation pipeline used traditionally for real-time graph-

Figure 2: Traditional 2D dose map (with axes removed). Reproduced with author's permission from [7].

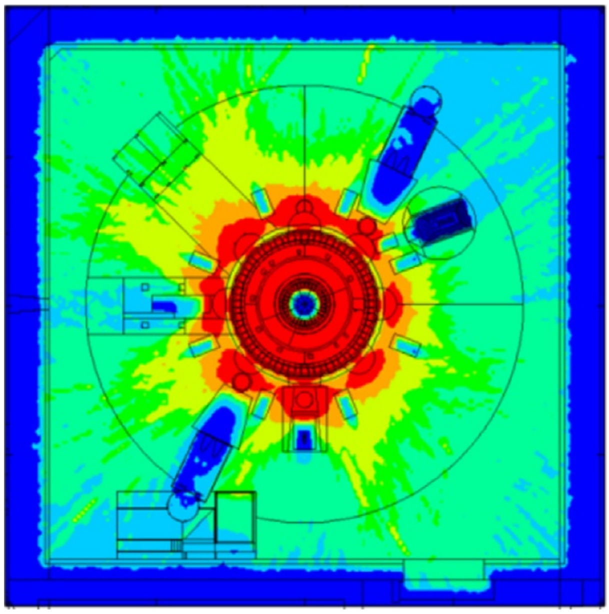
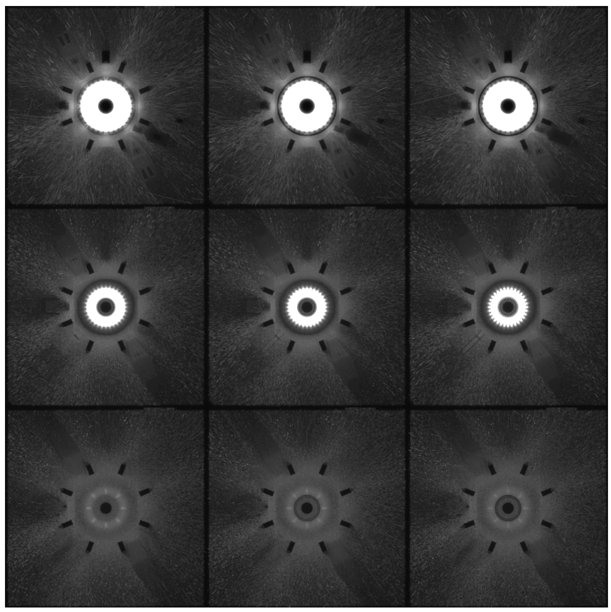


Figure 3: Subsection of an example 2D 32-bit float texture, generated from JET gamma dose simulation results in VTK format.



ics. A simple mesh such as a cube bounds the volume to be rendered, and is passed to the fragment shader where our method calculates each pixel colour. Due to the lack of commercial GPU support for 3D textures, volumetric data is pre-processed offline using a Python script integrated with UE4 to create a 2D RGBA texture. Shader programs are generated from a higher-level representation (UE4 materials) and use a custom ray-marching function to sample the volume texture at multiple, regular intervals along the camera vector at each pixel, with the object-space position transformed into texture-space and decomposed to 2D coordinates to index into the texture. Sampled values are decoded from four 8-bit integers (RBGA) into a 32-bit floating point value.

In the default configuration the accumulated value along all sample points is used as input to Beer's Law of light attenuation to calculate final opacity, thus approximating a volume of varying density (see Figure 4). Alternatively, a solid isosurface representation can be achieved by finding the shortest distance from the camera to a sample exceeding the configured threshold. This surface can then be shaded by calculating the surface normal by multisampling the volume along each axis (see Figure 6). The maximum value sampled is then used as input to a heat-map function that indexes into a colour scale texture to give the final colour (see 5).

4. Evaluation

The rendering technique has been tested in a traditional desktop setup with consumer-grade hardware and rendered to stereo in a more immersive setting with virtual reality headsets.

The application has been tested on input VTK files of a maximum resolution of 363^3 cells, resulting in a texture map of 7260^2 32-bit pixels. The default maximum texture size supported by the Unreal Engine is 8192^2, which is also the limit imposed by most consumer GPU hardware. This equates to around 268.4MB of raw color data before

Figure 4: Example of density effect - note lowered opacity around centre of the torus.

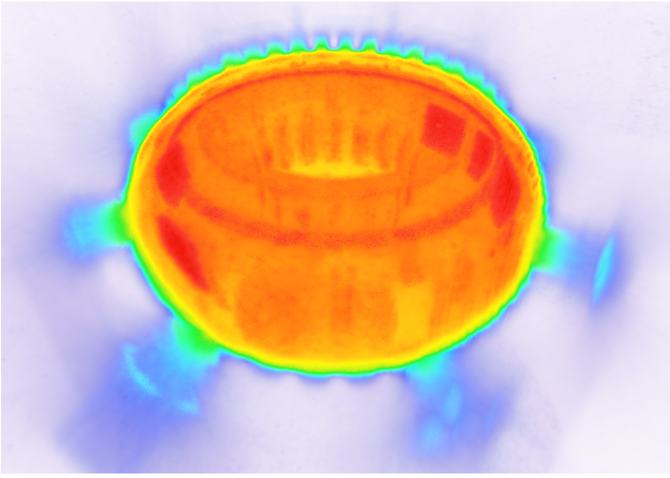
compression. A typical consumer GPU in 2018 has 8GB of onboard memory, implying that data of over around 24x the tested resolution could be used without requiring specialist hardware. However the limitation of maximum texture sizes would mandate development of a technique for looking up data from an atlas of textures, a form of virtual texturing. A novel feature of this method over rasterising meshes of isosurfaces is that render latency scales with the screenspace resolution rather than the volume of data.

The rendering technique has been tested in a traditional desktop setup with consumer-grade hardware and rendered to stereo in a more immersive setting with virtual reality headsets.

5. Future work

While targeted at rendering radiation fields for remote maintenance planning in nuclear fusion facilities, our method inherently generalises to the visualisation of any scalar quantity that can be sampled in a three-dimensional field, such as neutron dose, plasma density, temperature or pressure. Visualisation of plasma density could be achieved at very high resolutions by exploiting the radial symmetry of density profiles in tokamaks, allowing a single 2D texture of a radial slice to be used for the entire volume. The method is currently restricted to use with data that has

Figure 5: Example of heatmap colouration, where warmer colours correspond to a higher dose.



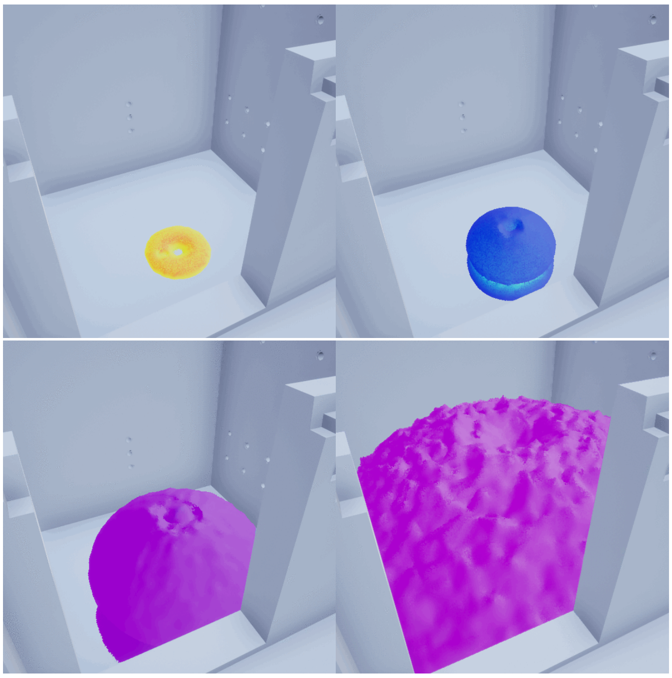


Figure 6: Sequence illustrating isosurface representation, with threshold decreasing left to right. Note the surface shading provided by estimating the normal at each pixel.

been pre-processed into a 2D texture. Extension to support online processing direct from VTK files or even live data streamed to the GPU seems feasible using UE4 render textures. For radiation dose visualisation this would be of limited use as dense 3D sensing of dose fields in real-time is not currently possible. However for other data such as plasma density, real-time visualisation is plausible.

References

[1] R. Buckingham, A. Loving, Remote-handling challenges in fusion research and beyond, Nature Physics 12 (5) (2016) 391.

[2] J. F. Briesmeister, Mcnp: a general monte carlo code for neutron and photon transport. version 3a. revision 2, Tech. rep., Los Alamos National Lab. (1986).

[3] R. Villari, P. Batistoni, S. Conroy, A. Manning, F. Moro, L. Petrizzi, S. Popovichev, D. Syme, J. E. Contributors, Shutdown dose rate benchmark experiment at jet to validate the three-dimensional advanced-d1s method, Fusion engineering and design 87 (7-8) (2012) 1095–1100.

[4] L. Snoj, I. Lengar, A. Čufar, B. Syme, S. Popovichev, S. Conroy, L. Meredith, J. E. Contributors, Calculations to support jet neutron yield calibration: modelling of the jet remote handling system, Nuclear Engineering and Design 261 (2013) 244–250.

[5] Y. Wu, F. Team, et al., Cad-based interface programs for fusion neutron transport simulation, Fusion engineering and Design 84 (7-11) (2009) 1987–1992.

[6] N. Sykes, S. Collins, A. Loving, V. Ricardo, E. Villedieu, Design for high productivity remote handling, Fusion Engineering and Design 86 (9) (2011) 1843 – 1846, proceedings of the 26th Symposium of Fusion Technology (SOFT-26). `doi:https://doi.org/10.1016/j.fusengdes.2011.04.004`. URL `http://www.sciencedirect.com/science/article/pii/S092037961100398X`

[7] J. Naish, A. Burns, Minimising operator dose during jet shutdown using virtual, Fusion Engineering and Design 124 (2017) 1215 – 1218, proceedings of the 29th Symposium on Fusion Technology (SOFT-29). `doi:https://doi.org/10.1016/j.fusengdes.2017.03.131`. URL `http://www.sciencedirect.com/science/article/pii/S0920379617303496`

[8] KitWare Inc., The ParaView Guide (2016). URL `https://www.paraview.org/paraview-downloads/download.php?submit=Download&version=v5.3&type=data&os=all&downloadFile=ParaViewGuide-5.3.0.pdf`