Virtual Reality Visualization Algorithms for the ALICE High Energy Physics Experiment on the LHC at CERN

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ABSTRACT

Analysing massive amounts of data gathered during many high energy physics experiments, including but not limited to the LHC ALICE detector experiment, requires efficient and intuitive methods of visualisation. One of the possible approaches to that problem is stereoscopic 3D data visualisation. In this paper, we propose several methods that provide high quality data visualisation and we explain how those methods can be applied in virtual reality headsets. The outcome of this work is easily applicable to many real-life applications needed in high energy physics and can be be seen as a first step towards using fully immersive virtual reality technologies within the frames of the ALICE experiment.

Keywords: computational geometry, stereoscopic 3D, physics visualisation, virtual reality

1. INTRODUCTION

To see is to understand - that phrase can serve as a perfect explanation of the role played by visualisation methods nowadays. The importance of visualisation becomes even more pronounced when we need to analyse massive amounts of data, such as those produced during high energy physics experiments. For instance, in the ALICE detector experiment,[1] one of the largest experiments in the world devoted to research in the physics of matter, petabytes of highly complex data are generated per each collision during experiment run. A typical approach to analyse this data is by using statistical analysis. Nevertheless, this approach does not allow the physicists to fully understand the processes occurring inside the detector, especially in terms of the trajectories of the particles during the collision and their properties.

To address the above-mentioned shortcomings of traditional analysis approaches, we propose to use visualisation techniques and, more precisely, stereoscopic 3D data visualisation methods to high energy physics experiments. Using these methods we are able to address several real-life use cases that are common in high energy physics experiments. First of them is the detection of acquisition process failures and errors. It is much easier to notice acquisition problems such as missing information from a given detector or from a given run, by simply looking at the visualisation of full particle trajectories in 3D space. Another use case of the visualisation methods is for training purposes. Being able to interact with the data through high quality visualisation, for instance using Virtual Reality glasses, significantly improves the cognition process and helps to imagine what is represented within the data. This, in turn, can lead to deeper understanding of physical phenomena and lead to major breakthroughs in the field.

In this paper, we propose to visualise 3D trajectories of particles using virtual reality. Following the recent advancements in the field of virtual reality, we implement and verify the feasibility of various visualisation methods when applied to virtual reality headsets. Although main use of the headsets is entertainment, we believe that they can provide interesting insights into highly complex and massive data collected during high physics experiments, such as ALICE. Previous works suggested using standard visualisation hardware, such as monitors and 2D screens,[2,3] due to the cognitive discomfort experienced by the users of virtual reality headsets. In this paper, we present several methods to minimise this discomfort by compensating for the distortion characteristic

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for virtual reality headsets. Our main contribution is a comparison of those methods and their deployment on an Oculus virtual reality headset.[4] At a current state, we consider this visualisation setup as an interesting complement to solutions based on more standard hardware, but with the next generations it may become the primary analysis tool.

The remainder of this paper is organized in the following manner. In Sec. 2 we give a brief overview of the related work. Then, in Sec. 3, we describe the virtual reality display used in our experiments and describe its intrinsic distortions. We then explain how those distortions can be handled using proper post-processing methods. We conclude the paper in Sec. 4.

2. RELATED WORK

In this section, we give a brief overview of the literature related to virtual reality and visualisation. Although a lot of attention was paid to the topic of virtual reality within the last few years, the application of virtual reality visualisation in high energy physics has not attracted a lot of attention from research community. We therefore believe that this work will serve as a first step towards using virtual reality methods and headsets for the purpose of visualisation of complex and massive amounts of data collected during those experiments, including 3D particle traces and similar.

Virtual Reality

The availability of affordable virtual reality headsets has lead to a proliferation of multiple virtual and mixed reality applications.[5] One notable example of such applications is ParaView - an open-source multi-platform data analysis and visualisation tool.[6] Other solutions can be used to enable intuitive and seamless human-computer interactions.[7–9] They can also be applied to solve the problem of analysing very large datasets.[10,11]

Visualisation in Physics Experiments

Visualisation plays a very important role in physics. It is typically used to present mathematical concepts linked to physical phenomena, such as magnetic fields, but not the phenomena themselves.[12] Only a limited number of works have actually focused on visualising physical processes. One notable example is a system to visualise plasma[13] using a computer graphic particle system.[14] Contrary to the approach proposed in this paper, typical solutions focus on using monitors for visualisation, but recently several attempts have been made to also include virtual reality hardware for these purposes.[15]

Track Visualisation

One of the most interesting types of data to be collected and analysed during physics experiments is a 3D reconstruction of the particle traces. This type of data is typically registered during high energy physics experiments that include colliding particles. One of the most renown experiment of this kind is the ALICE experiment done on the Large Hadron Collider at CERN.

There are several approaches to visualize particle traces in collider experiments, from displaying 3D point clouds[16] to visualising their tracks together with the geometry of the detector.[17] In ALICE, we are able to register and store data on individual trajectories and high quality detector geometry. Therefore, a visualisation tool to display those traces along with the simulation of the detector interior was implemented. This visualisation tool helps to recognize malfunctioning part of a detector in case of its failure or a missing trajectory data, if that situation occurs. This tool, however, provides a limited 2D visualisation and is currently used in the so-called *control room* for data quality monitoring purposes.

Visualisation in Alice

The main purpose of visualisation in the context of ALICE experiment is to monitor the quality of the collected data.[18–20] In fact, technical, and not physics, analysis is the main reason to use complex visualisation systems at ALICE.[18] Further information on the placement of visualisation tool within the entire data acquisition system is thoroughly describe in[21]

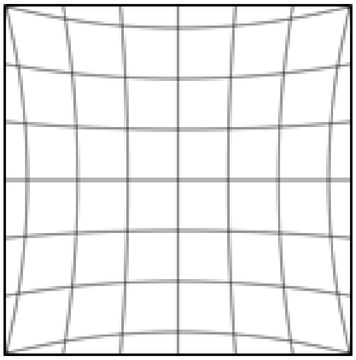

Figure 1: Pincushion distortion introduced by lenses in VR Headset[4]

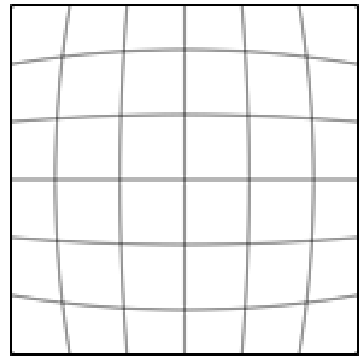

Figure 2: Barrel distortion required to compensate FOV lens[4]

Previous Work

In previous publications,[2,3] we proposed monitor-based solutions for trajectory visualisation. The main reasoning behind this design choice was that using virtual reality headsets for extended periods of time can potentially lead to severe headaches and other symptoms of cognitive discomfort. Quality of the observed scenes in terms of resolution is also not perfect yet. It may be not so important in entertainment visualisations, but thin lines used for track visualisation suffer badly. In this paper, we present several methods to minimise this discomfort by compensating for the distortion characteristic for virtual reality headsets.

3. HEADSET DISTORTION AND ITS COMPENSATION

In this section, we first introduce the Virtual reality headset used in our experiments and explain the distortions that can be observed when using the headset. We then present three methods to compensate the headset view distortions along with the visualisations of their results.

3.1 Virtual Reality Headset

Virtual Reality Headset is typically equipped with two lenses, which provide a very wide field of view (FOV) that enhances the sense of immersion. Although the internal display of the headset may be flat, the content presented on the display should seem three-dimensional and therefore should the visualisation system should compensate for the distortion introduced by headset lenses. Without the compensation the user would observe content with pincushion distortion, as presented in Fig. 1.

To compensate for this distortion, the visualisation system must apply post-processing step to the rendered content with an equal and opposite barrel distortion. Parameters of that post-processing step should be established in such a way, that the two transformations cancel each other out, as presented in Fig. 2.

3.2 Scene Rendering

To render a scene into a virtual reality headset, we can use any of the OpenGL rendering schemes and run it twice from transposed observer locations. This way, we are able to generate two views of the scene that correspond to the left and right eye views. The resulting texture may be then displayed using GLSL fragment shader which computes barrel distortion as shown in Fig. 3.

This approach is fairly simple to implement, but achieves poor quality in terms of resolution, especially noticeable for thin lines as presented in Fig. 6). This is caused by the interpolation step that takes place in the last stage of the algorithm, when texture is used to produce barrel distortion. A close-up image shown in Fig. 5 presents the resulting distortions.

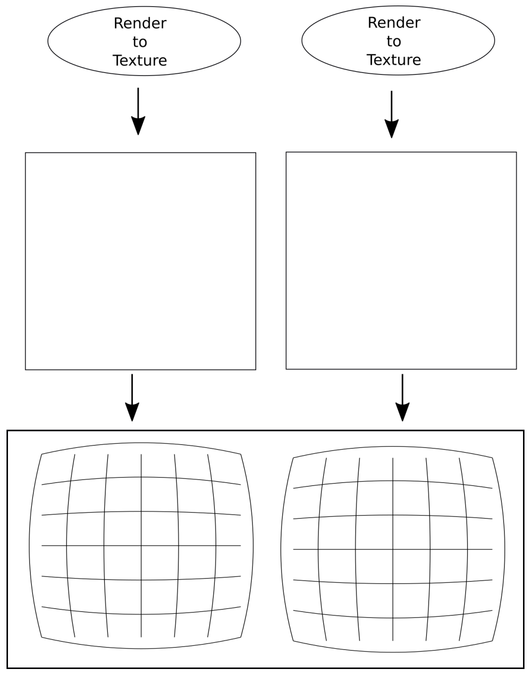

Figure 3: Drawing using two textures and OpenGL fragment shader.

3.3 Texture with Smoothing

The above-mentioned problem can be mitigated by introducing more complex texture sampling or enabling line smoothing. Fig. 5b and 7 show the results obtained with line smoothing. The quality of the results has been significantly improved and the distortion of the headset rendering was reduced. Nevertheless, this approach requires significant computational time, noticeable especially for line smoothing. As a result, the rendering time may be too long for the low-cost or integrated graphic cards.

3.4 Bezier Splines

Tracks are defined by the list of points. They can be connected using straight lines or by the application of Bezier Splines. Since particle tracks to be visualised are defined using several dozen points each and direction of the adjoining fragments are similar it is hardly to notice any difference between both solutions. It become visible when single track is analysed. This condition justifies usage of Bezier splines in track visualisation.

3.5 Vertex Shader

To address the computational cost constraints mentioned above, we could avoid computing the textures completely and draw barrel-distorted rendering from the beginning. This approach requires deeper modification of the rendering pipeline, since vertex positions have to be altered for proper visualisation. This operation can be easily implemented with the *so-called* vertex shader. Avoiding drawing the texture allows us to obtain undistorted rendering as shown on Fig. 8 and close-up on figure 5.

This approach, however, has several limitations, not to be discarded. The most important problem occurs when size of the draw primitive is too big and the distortion cannot be treated as linear, which can be seen in the upper part of Fig. 4. A solution of this problem is to divide primitives so their distortions can follow distortion of the larger part, as shown in the lower part of Fig. 4. Nevertheless, in the case of particle trajectory visualisation, the problem with non-linearity of the distortion is not relevant since each track is represented using several dozen points data points. If user-controlled zooming functionality is limited and the scene cannot be zoomed above certain level, the issue is not to occur. We, therefore, believe that using vertex shader is the most efficient and quality-preserving method for distortion compensation in virtual reality headsets we evaluated.

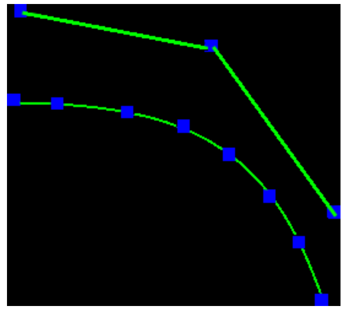

Figure 4: Inaccuracy of the tracks as a function of a number of the segments in vertex shader method.

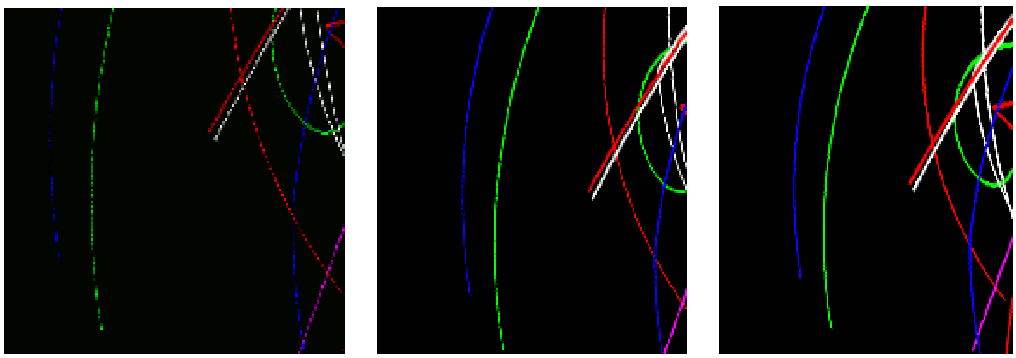

Figure 5: Close-up of the track for texture (a), texture with smoothing (b) and vertex shader solution (c).

4. SUMMARY

In this paper, we described and compared several approaches for compensating the distortion occurring in virtual reality headsets used to show particle traces in the ALICE experiment at CERN. We identified a problematic test case of the visualisation system, namely the scene with multiple thin line dataset to be displayed. To solve this problem, we tested several methods, including Bezier Spline approach and we identified the approach based on vertex shader to provide the best performance. Although using it can potentially complicate the development and testing of our virtual reality system for data visualisation, it is the preferred choice since it does not degenerate the quality of the scene and nor does it bear significant computational costs.

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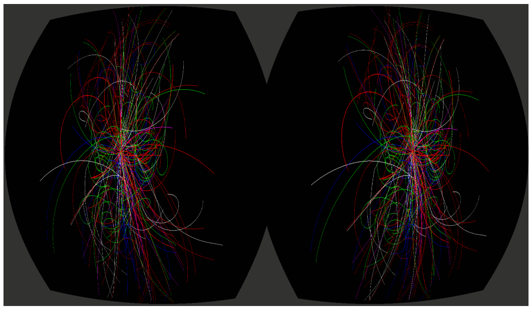

Figure 6: Tracks displayed using texture method without any compensation method.

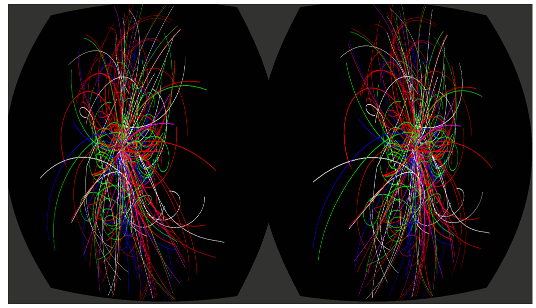

Figure 7: Tracks displayed using texture method with line smoothing enabled.

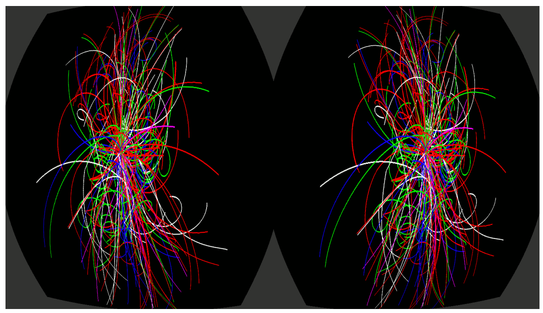

Figure 8: Tracks displayed using vertex shader method.

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