A study of Perception of volumetric rendering for immersive scientific visualization

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ABSTRACT

In this work we study the perception of volumetric data in an immersive Virtual Reality environment. The objective is to study the limits of volumetric rendering, using point clouds, for the display of scientific volumetric data, such as temperature distribution in a car interior. We investigate the effect on the users perception of three properties of the cloud point volumetric rendering: point size, cloud density, and near clipping plane position. We present an experiment where a series of pointing tasks are proposed to a set of users. User behavior and task completion time are evaluated during the test. The study allowed to choose the most suitable combination of these properties, and provided guidelines for volumetric data representation in VR immersive systems.

Index Terms: H.6.1 [INFORMATION INTERFACES AND PRESENTATION (I.7)]: User Interfaces (D.2.2, H.1.2, I.3.6)—Theory and methods; H.5.1 [INFORMATION INTERFACES AND PRESENTATION (I.7)]: Multimedia Information Systems—Artificial, augmented, and virtual realities.

1 INTRODUCTION

1.1 Virtual Reality for scientific visualization and interaction

Virtual and augmented reality are now successfully work in the design process of large industries such as the aeronautics, automotive or the energy industry, with applications at various levels: Computer-Aided Industrial Design (CAD), Computer-Aided Manufacturing (CAM), Computer Aided Engineering (CAE). VR immersive techniques are also used for scientific visualization, either for design, research or communication purposes. Scientific visualization often involves complex data and rich models which involve multi-dimensional parameters. This challenges the virtual reality community for innovative immersive representation techniques, as well as adapted interaction methods. The question of the perception of complex data, especially regarding visual feedback, is an open question, and it is the subject of this work.

VR environments are commonly used to represent objects and worlds, and therefore their design is essentially driven by the needs for realistic rendering. Such design guidelines are no more available when VR is used for complex data visualization. The objective in this case is not to be realistic, but to provide new and intelligible ways for model representation. This raises new issues in data perception.

The industrial use of virtual reality data exploration tools is to find out potential design flaws at an early stage of design. One of the main important uses is to allow the user to perceive specific phenomena, understand data values and be able to look for local maximum or minimum values of the represented data.

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In view of this objective, visualization systems are meant to represent data comprehensively have been proposed by researchers.

Some immersive applications use 2D or 3D plots, integrated in the 3D world, as representations of functions of one or two variables. Statistical curves, data histograms, 2D/3D areas are used to represent additional information to better understand scientific models associated with 3D objects, as it has been done by Bjorn and al. [11]. The authors propose to represent 2D data which can inherently be better visualized in 2D, such as a pie chart, soil columns or log plots of rock types based on the user's request on 3D objects in the virtual environment.

Immersive systems provide the advantage of depth perception and intuitive real time manipulation of various parameters that makes VR more interesting to represent 3D or more complex data and models.

Representation of scalar data in a 3D space has been used in various contexts. In the medical field, volume rendering and cloud points have been used to represent medical imaging data, as a color set of points in space, where the user can perform data exploration actions. Hinckley [4] proposed a setup where the user can manipulate real props to control a cutting plane through a visualized volumetric rendering of MRI data. In earth environment sciences, Bernd and al. [2] presented new ideas for the exploration of a scalar volumetric grid data from the oil and gas industry in interactive stereoscopic virtual environments. A novel input device, the cubic mouse, which literally puts the seismic cube (a cube-shaped, tracked input device) into the user's hand and allows very intuitive control of viewing parameters, facilitates the exploring interaction.

For the representation of more complex data, such as 3D vectors fields and computational fluid dynamics (CFD) models, several representations were proposed:

- Moving 3D arrows: 3D arrows proposed by Schulz and al. [8], a visualization tools which incorporates virtual reality techniques for the interactive exploration of the large scalar and vector data sets is developed. Fast 3D arrows particle tracing are used to take into account collisions with the car body geometry.
- Streamlines: Tamer and Ahmed proposed [10] to integrate CFD simulations to a Virtual reality environment, CFD simulated phenomenon are represented in streamlines can help visualize the flow and its effects on the model, the VR system allows natural and fast exploration and the visualization of the flow that can help optimize the configuration and geometry of the designed systems.
- Isosurface: Visualization of complex grid data in geosciences is performed by Oliver and al. [5], where isosurface and streamlines are used for a numerical simulation the earth's mantle flow in a stereoscopic head-tracked visualization environments.

Some studies have been proposed, that deal with the efficiency of data representation for scientific data:

- The question of how to map the values of a variable onto a color scale has been previously addressed. A commonly used mapping proposes is a color-based scale starting from blue, through the colors of the rainbow to red proposed by Rogowitz and al. [1]. They found that when a rainbow scale is mapped onto scalar data, the user is conceptually mapping a linear scale in hue onto a scalar variable. Perceptually, however, this scale does not appear linear. Equal steps in the scale do not correspond to equal steps in color. This can lead the user to infer a structure that is not present in the data and to miss details that lie completely within a single color region. Lawrence and al. proposed an architecture called PRAVDA incorporating guidance based on principles of human perception, cognition and color theory [1]. These principles are incorporated in rules which the user can select during the visualization process.

- Lum and al. [7] have presented a novel visualization technique-kinetic visualization that uses motion along a surface to aid the perception of a 3D shape and structure of static objects. The method uses particle systems with rules such as particle flow over the surface of an object; it does not only bringing out, but also describes flow information on a shape that might not be easily visible with a conventional rendering method which uses lighting and view changes.

These works focus on the perception issues on 2D images, 3D shapes and objects. In this work we want to better the visualization of volumetric data. To our knowledge few studies have been performed to address the perception issues in a scientific visualization context, regarding complex volumetric data.

Can we have guidelines for VR visual representation of volumetric scalar temperature data, in terms of data density, size of visualization elements? Another question, is the role of the size and position data volume, relative to the user, and the physical display? Virtual reality display techniques are likely to make this question a central one. Does the user understand represented the data? These are still open questions.

In the next section we will point out some of the key features of VR visualization, e.g. depth and stereo perception. We will then select relevant visualization conditions to study. For the study, we propose a user pointing task that we describe in section 3. Finally, we discuss results of the study with a focus on section 4 and 5.

2 VR IMMERSION ENVIRONMENT CHARACTERISTICS

Before discussing the approach of our study, we need to define important concepts for stereoscopy and visualization in VR systems. VR immersive systems allow the user to perceive depth information classically by means of stereo glasses and a head tracking system. These are considered as the main techniques meant to achieve depth perception and perspective in virtual reality. However, depth perception, stereo fusion and user comfort depends on more parameters [6].

First, depth perception is possible in a monoscopic vision, that is, a vision with one eye. A number of visual clues, relying on a cognitive activity, allow the brain to reconstruct depth information. Size: for a given object, its apparent size is a function of its distance to the eyes, farther objects appear smaller. Occlusion: an object that covers another is expected to be in the foreground. Shadows can give a depth clue. Texture gradient: closer objects represent more detail than distant objects and further objects. Movement Parallax: speed of movement of an object image on the retina depends on the object's depth [3].

Stereoscopic perception in everyday life stems from retinal disparity. Stereoscopic images in a VR environment are produced by rendering two images one for each eye, with a technique of two asymmetric frustums associated to two cameras which are separated by a distance corresponding to the user's inter ocular distance.

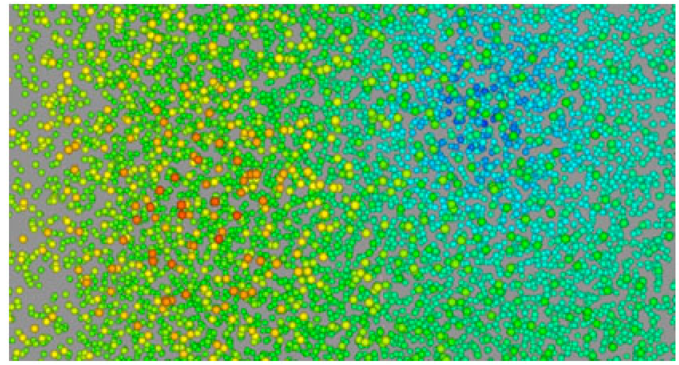

Figure 1: cloud points in 3D space

Of course, the stereo perception simulated in VR has its differences and limitations compared to real life stereoscopic perception.

Accommodation is the process in which the fixated point of the crystalline lens changes in order to focus at a particular depth. Convergence is the extent to which the two eyes are turned inward towards to an object. In everyday vision, accommodation and convergence are consistent and adapted to the fixated object. With VR displays, there is a discrepancy between these two phenomena: convergence is still there on the objects, while accommodation remains fixed on the screen surface.

Parallax is the distance between two equivalent points in the two displayed images. The main limitation of perception in a VR environment is caused by unadapted parallax, since it can impact on stereoscopic fusion. In our VR immersive environment, the objects are projected on the screen. When the point being projected is behind the projection screen, it is a positive parallax, on the contrary situation, when it is in front of the projection screen, it is negative parallax. As the object moves towards the user the negative parallax rises higher.

Fusion limitation [9] defined a parallax limitation angle. His research indicated that, for easy fusing by the majority of people, the absolute value of parallax limitation angle should not exceed 1.5 degrees for all points in the scene.

In this work, we want to investigate fusion limits for volumetric rendering. Volumetric rendering, is a set of data points in 3D space, where the points represent a given scalar value, temperature or other properties of different colors. See Figure 1.

When using cloud point representation techniques in VR environments, the consideration of fusion limits are important. The cloud point can be influenced by fusion limits in several ways:

- Too large parallaxes impede stereoscopic vision;
- If the points are too close to users, fusion is not easy to achieve;
- Large points reduce resolution;
- Point density;
- Appearance of moiré pattern, which is likely to appear in a periodic display of points and can also impede visual perception of such data.

On this basis, in order to assess user perception and precision, a point task is proposed to investigate the influence of three visualization parameters on perception of volumetric data:

- Point size: sample point size of point cloud is the size used to describe one single 3D point. Since VR systems are calibrated

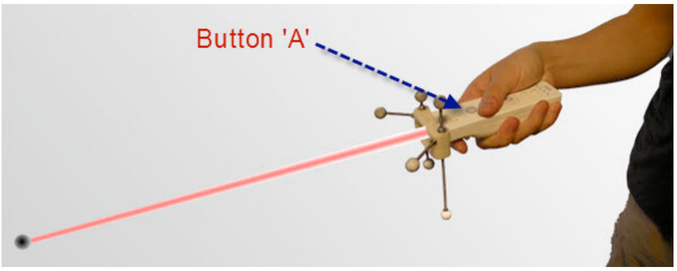

Figure 2: Control and tracking device, with virtual cursor, used in the experiment

to allow scale 1 representation, we can specify this size in the metric system. We have performed an informal test on various point sizes and observed that: too large a point size seems to lower resolution and comprehension of 3D scalar data representation. On the contrary, small size of points allows higher resolution, by increasing point density; however stereo fusion of small-sized points seems difficult for a certain threshold.

- Density is another way of changing cloud point resolution. High density of cloud points gives better stereoscopic vision but covered background information; On the contrary, low density reduces the resolution and stereoscopic vision precision.
- Near clipping plane position of cloud points defines the distance between the subject's eyes and the first visible point of cloud point, it associated parallax of human eyes which influences stereoscopic fusion. This means closer near clipping plane position causes user stereoscopic fusion problem and makes their eyes feel uncomfortable.

3 Experiments

3.1 Objective

For the test we propose a series of pointing tasks, where the users have to point out in 3D space maximum and minimum temperature areas represented in a color cloud points field. Thus, we assess the ability of point cloud volumetric rendering to provide good comprehension of the data. We mean to address the questions of: how the point size, density and near clipping plane position influence stereoscopic vision? What is the best combination of these three parameters for providing an efficient and precise enough data review tool?

3.2 Setup

The immersive VR system setup used in our study is a wall type stereoscopic display, with a 3.1m by 1.74m screen size. A Christie HD3 projector is used for rear projection on the screen with a 1920 by 1080 resolution, at a 24-bit color setting. The system provides stereoscopic visualization. Image separation for each eye is achieved through Crystal Eyes active stereoscopic glasses.

The tracking of the user's head and dominant hand is performed with an optical Tracking system (AR Tracking). A dynamic point of view is computed using the classical asymmetric frustum technique. This, combined with precise calibration of the system to the user's interpupillary distance, allows a scale 1 display of virtual scenes. This is a requirement for our experiment. A wireless device is used for application control and it is held by the user in his dominant hand, so he can press a confirmation button with his thumb. The hand tracking markers were embedded in the hand-held device (wiimote)so the user does not wear any device. See Figure 2.

The whole testing scene in the experiment is generated with an Open GL 2.0 render engine, using an Nvidia Quadro FX 5600 GPU. The refresh rate is 60Hz; active stereo is used throughout the experiment. The users are standing approximatively at a distance of 1.2m distance from the screen but they are allowed to move freely to benefit from a dynamic point of view enabled by head tracking.

3.3 Task description

To investigate how to provide a perceivable and understandable 3D cloud point in an immersive VR system and what the precision of user perception of the temperature distribution in 3D space is, we propose a pointing task experiment.

The user has to point at two locations in space: the coldest source (0°C), and the hottest source (100°C), which are placed randomly within the cloud point volume. Again, the temperature field is represented as a cloud of points; each point is colored to represent a temperature. The color and temperature mapping is obtained by a typical rainbow color map, as the coldest point is blue (R: 0 G: 0 B: 255) and the hottest point is red (R: 255 G: 0 B: 0). The remaining points, which are not influenced by the cold and hot source, are set at a constant temperature (50°C) corresponding to green(R: 0 G: 255 B: 0). Around the hottest and coldest sources, a radiant effect is interpolated and presented as a continuous variation in temperature from the local maximum or minimum to the uniform (50°C) temperature. See Figure 1.

For the pointing task, a virtual pointing cursor is displayed at the top of the handhold device; it is a 100cm long cylinder, with a visual tip at the end. This tip is used for pointing at the coldest and hottest source. The reason for displaying the 100cm tip away from the hand is to avoid bias due to occlusion by the users hand on the task. The users have to point at the point in space which they believe to be respectively the coldest and the hottest source, by using the virtual cursor.

3.4 Experimental conditions

To analyze volumetric cloud point perception, we propose focusing on three important parameters: density, point size and near-clipping plane position.

Density defines how many 3D points are placed in an existing in cloud point along each axis (e.g. X-axis, Y-axis and Z-axis). In the present experiment, we define a cubic cloud point area which is 2.3m×2.3m×2.3m. This is a linear density that could take 3 values: 7 points/meter, 13 points/meter and 20 points/meter. See Figure 3.

Point size is the diameter of each point. All the points are displayed by using sprites with a round texture whose center is white and the border is black on the alpha channel. Thus each point is not a complex spherical mesh. Three different diameters are compared in our experiment: 15mm, 20mm and 25mm. See Figure 4.

Near clipping plane position of a cloud point defines the distance between the subject's eyes and the first visible point of the cloud point. See Figure 5. Three different conditions were applied in our experiment are: 0.6m, 0.9m and 1.2m.

Each user was presented with all combinations of these three parameters (3 different densities×3 different point sizes×3 different clipping plane positions) yielding 27 different experimental conditions. For each user a random sequence of these conditions is generated as a pre-computed data array, stored for data analysis. For each condition, one hottest source and one coldest source are randomly placed within the cubic cloud point area. Overall, there were 27 different stimuli conditions, each subject performing 54 pointing tasks.

3.5 Implementation

Stimulus in our tests is based on the cloud point, visualized in a cubic volume. In order to enhance human stereoscopic visualization we rendered the cloud point using a GPU shading computing color and size of each point:

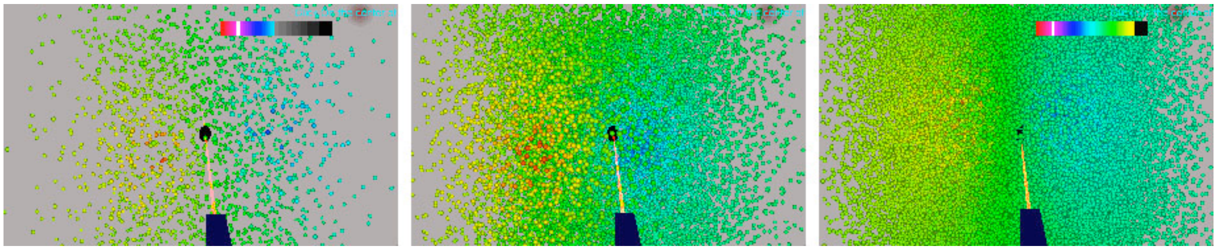

Figure 3: Different cloud point densities.

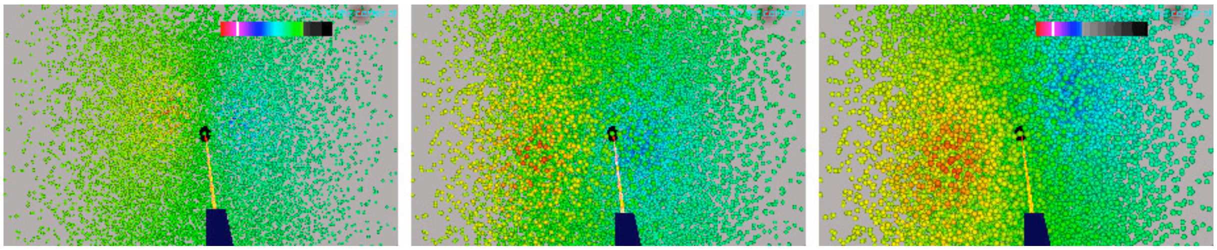

Figure 4: Different point sizes.

- **Shading:** Each point has a diffuse color, but it is not uniform on its surface, a gradient is applied to increase contrast between points. This gradient was added because in a uniform temperature area the points were visually difficult to distinguish. The gradient is radially applied to each point, See Figure 6. All the points are displayed by using textured sprites, thus each point is not a complex mesh.

- **Point size:** Attenuation defines how the size of 3D points change with respect to its distance from the viewer. The following equation 1 is applied to point size attenuation computation.

$$ObjectSizeOnScreen = ObjectSize * \frac{Dis(UserToScreen)}{Dis(UserToObject)} \quad (1)$$

- In a first test, we have observed moiré patterns in the point cloud.See Figure 7. Moiré patterns appear when grids are overlaid, which is the case in our volumetric display method. These Moiré patterns caused discomfort during visualization and we have proposed a method to remove this effect. It consists in slightly spacing out each point centered on its theoretical grid position, in a randomly chosen direction. The random displacement value is chosen between 0 and theoretical two neighbor intervals. Moiré patterns were totally removed with this method.

- A Shader technique was used to deal with large amounts of graphical data. An OpenGL Vertex Shader is applied to the point cloud. The size, temperature and color mapping of each point are implemented in the GPU Shader. The temperature model is based on a linear interpolation on the grid, based on the two maximal and minimal values (hot and cold points in space): When a heat source is placed in the cloud point, the temperature of surrounding spatial points is computed by Inverse Distance Weighted Interpolation (IDW). IDW is a commonly used technique for interpolation of scalar temperature points. It is based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points. The following equation 2 is used on the cloud point to map temperature on the grid and recreate a temperature distribution to be displayed in the immersive VR system. Where $z(x_p)$ is the interpolated value at the point, n is the number of data points, $z(x_i)$ temperature value of heat source, d is the distance between the interpolated points and heat source, k is the distance weighting.

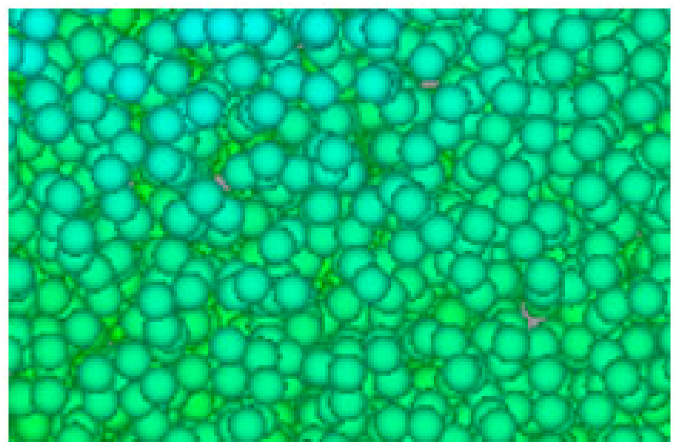

Figure 6: Gradient effect applied on each point using a shader.

$$z(x_p) = \frac{\sum_{i=1}^{n} z(x_i)\frac{1}{d^k}}{\sum_{i=1}^{n}\frac{1}{d^k}} \quad (2)$$

We evaluate human stereoscopic vision performance with the point cloud being the only object displayed. See Figure 8. The experiment was carried out by 12 subjects, aged 22-33 years old, and all of whom had normal or corrected visual acuity and stereo acuity was assessed using the Wirt test.

The subjects were asked to stand 1.2m away from the screen, and were free to move in the VR immersive environment. Each subject performed a total of 27 (3×3×3) stimuli tests and these conditions was randomly performed to subjects.

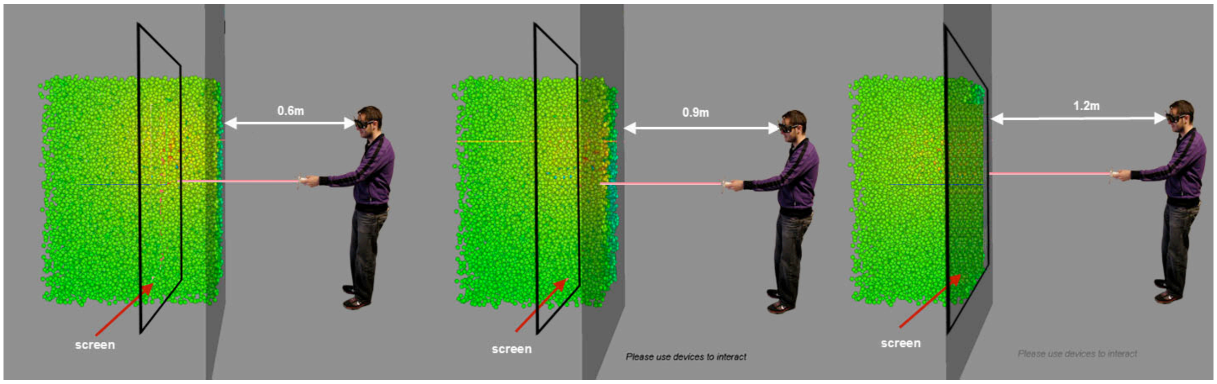

Figure 5: Different near clipping positions.

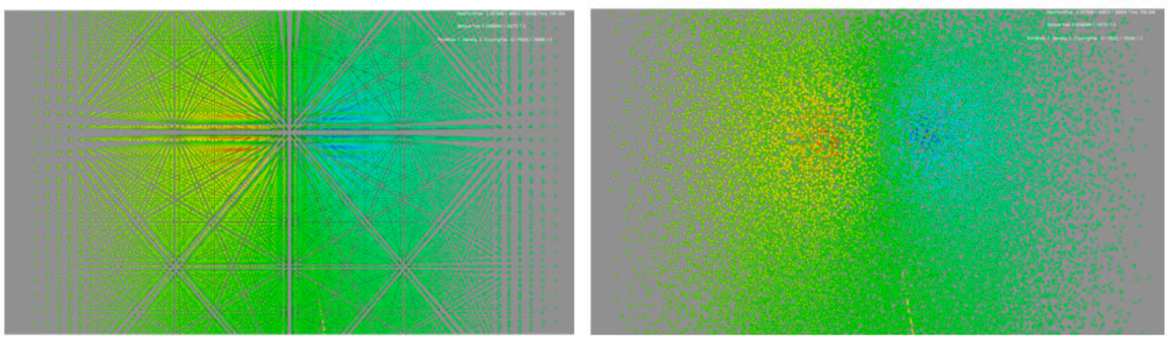

Figure 7: Left: evenly distributed points: appearance of moiré patterns. Right: adding a noise in point placement cancels the patterns.

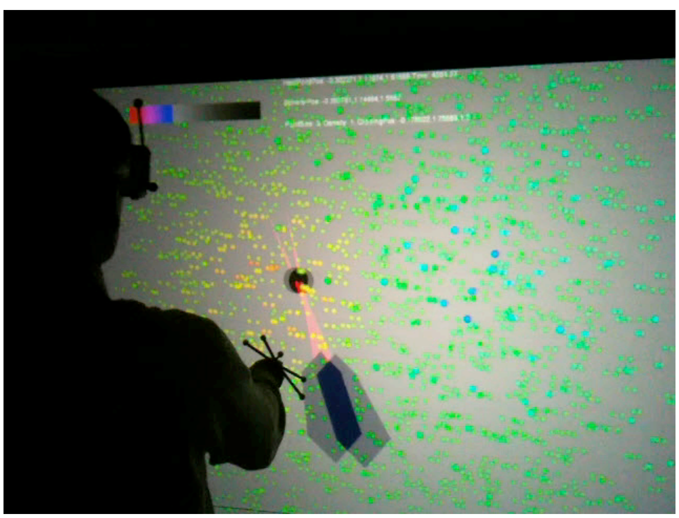

Figure 8: Experiment on cloud point.

The subject has to complete the pointing task using a virtual wand which has a tip at its end (3D sphere). This tip is used to point at the position where the user believes the centre of hot source and cold source are located. The subjects were instructed to carry out the task as accurately and as quickly as possible.

There are two measuring criteria in our experiment:

- The time between target display and target pointing with button confirmation, stopping the timer.
- For each pointing task the error distance is recorded: it is the distance between the theoretical centre of the hottest or coldest source point and the pointing sphere position at the time of clicking.

Participants training: At the very beginning of the task, the subject performs a set of training tasks. This training is used to familiarize the subject with the experiment environment and manipulation.

Two different experiments were conducted, one with no 3D environment surrounding the data, the second in a car interior environment. The objective is to investigate if the presence of a 3D scene, affects the performance in any way. This is meant to assess the nominal use of such visualization techniques, where the 3D environment that the data is related to will be displayed. Below, we will refer to these two conditions as 'with or without 3D scene'.

4 Results

- **Subject training**

  In the training part, one condition among the 27 possibilities is randomly chosen; This is repeated 9 times, yielding 18 pointing tasks (hottest and coldest targets). We measured the task completion time.

  Figure 9 illustrates that the completion time curve decreases over the sequence of tasks, showing that users acquired experience throughout the training procedure. On the graph we compare task completion time during the training procedure and the average completion time measured in the real test.

Figure 9: Subjects training results.

Source	Sum Sq.	d.f	F	Prob>F
PointSize	0.000035	2	5.24	0.0148
Density	0.00687	2	101.96	0
N.C.Plane	0.00006	2	0.88	0.4317
Total	0.00796	26		

Table 1: Experiment 1 in error distance (manova).

Training session was held once for each subject, before the real experiment.

- **Experiment without 3D scene**
  In each experimental condition, we evaluate the pointing time and the spatial error distance by taking the average of the two pointing task (hottest and coldest) manipulation results.
  Table 1 represents the pointing error in meters, for all experimental conditions (density, size, and position of clipping plane).
  Table 2 represents pointing time in seconds, in all experimental conditions. We performed a multi-factor analysis of variance on the 3 experimental conditions. Results show a significant influence of Point size on error distance $F(2,20)=5.24$ $p=0.0148$.There is also a significant influence of Density on error distance, $F(2,20)=101.96$ $p<0.001$. Finally, there is no significant influence of near clipping plane position on error distance.

  For the task completion pointing time, the Clipping plane position has a significant influence on task completion time $F(2,20)=6.67$ $p=0.006$.

- **Experiment with 3D scene: car interior** In the second experiment, a vehicle interior model, with a 1:1 scale, was present on the scene. We filled the vehicle cabin with a point cloud to represent a temperature distribution within the vehicle. See Figure 12.

Source	Sum Sq.	d.f	F	Prob>F
PointSize	158874.9	2	1.39	0.2724
Density	260744.7	2	2.20	0.1203
N.C.Plane	762209.7	2	6.67	0.006
Total	2326911.4	26		

Table 2: Experiment 1 in time taken (manova).

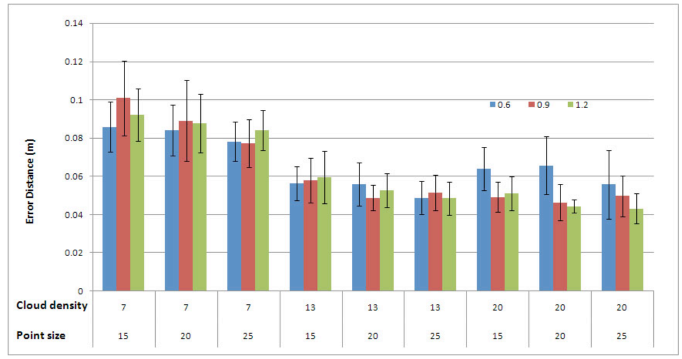

Figure 10: Pointing error (m). Experiment with no 3D scene.

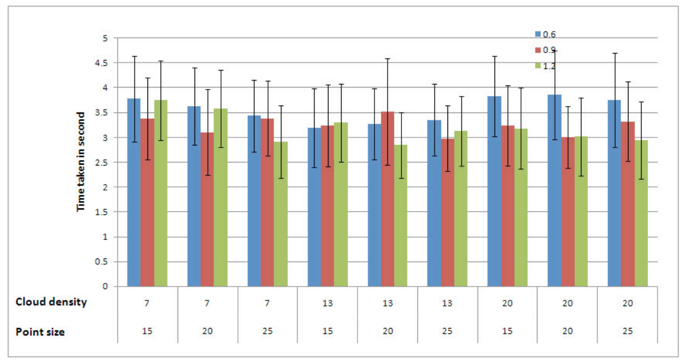

Figure 11: Pointing task completion time (second). Experiment with no 3D scene.

In this experiment, the conditions and tasks were the same as in the "without 3D scene experiment". Figure 13, Figure 14 and Table 3,Table 4 show that user performance did not change significantly, compared to the experiment 1: when density is low and size is small, users produced high spatial error distance and took more time for pointing.

Source	Sum Sq.	d.f	F	Prob>F
PointSize	0.0002	2	1.83	0.1867
Density	0.00666	2	59.89	0
N.C.Plane	0.00014	2	1.3	0.2958
Total	0.00812	26		

Table 3: Experiment 2 in error distance (manova).

Source	Sum Sq.	d.f	F	Prob>F
PointSize	158974.8	2	1.39	0.2724
Density	261743.8	2	2.20	0.1203
N.C.Plane	762209.8	2	6.67	0.006
Total	2336011.0	26		

Table 4: Experiment 2 in time taken (manova).

5 DISCUSSION

In our experiment, we focused on cloud density, point size and near clipping plane position.It was observed that:

- Point size and cloud density, have a strong effect on precision and completion time.

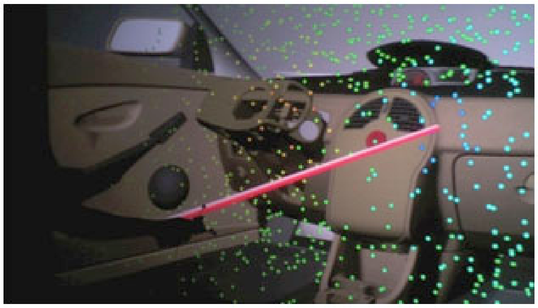

Figure 12: Experiment with 3D scene.

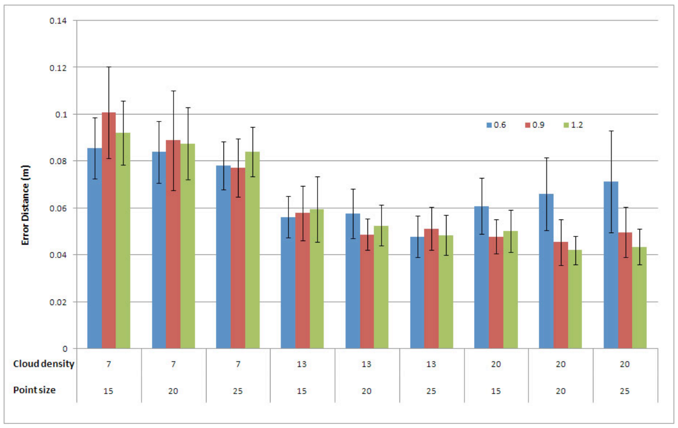

Figure 13: Pointing error (m). Experiement with 3D scene.

- Clipping plane position does not have a significant influence on precision; however it has a significant influence on completion time. Our hypothesis is that situations where the clipping plane is closer to the user, induce more user-fatigue due to higher parallax. Hot and cold target sources where placed within an area that extends from 0.6m to 1.2m. Thus, during the pointing task, the user eyes converged within this area. However, when the clipping plane was close to the user, more objects with large parallaxes were displayed, this is known to induce higher user-fatigue [6] [9].

- One intuitive hypothesis was that an increased density would increase pointing precision; however this is not the case. We observe on Figure 15, that user precision does not get better in the high density cloud condition compared to medium density. Measured precision also has a much higher standard deviation for the highest density. A plausible explanation for this is that beyond a certain density, the occlusion effect of background points by foreground points impedes perception of further visual information and thus impedes task efficiency. Below different display techniques meant to counter this effect is discussed.

- Best combination: The best user performance was observed in the farthest clipping plane position, with medium density and large point size (clip = 1.2m, point size = 25mm, 13 points per meter). The effect of low precision on low density yielding is intuitive. However, the experiments suggest a threshold for density beyond which user precision does not improve.

- Experiment with 3D scene: It was observed that the addition of the 3D scene has no significant influence on user performance; it appears that the comprehension of data is not impeded when the related 3D environment is added. However, this depends on background color and contrast. This issue needs more investigation, i.e. to take into account metamerism error effects that can change the perception of colors depending on the background.

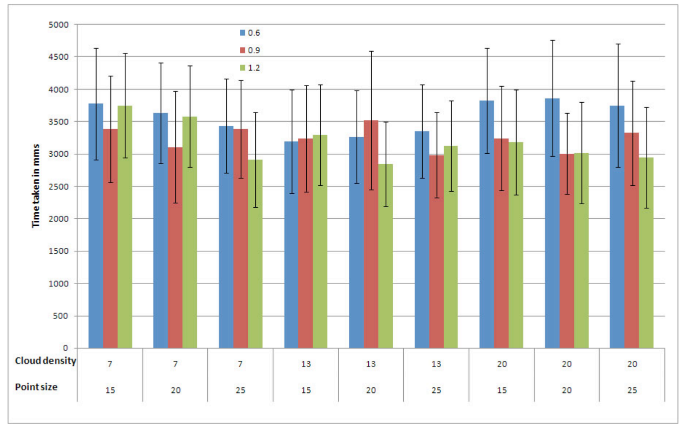

Figure 14: Pointing task completion time (second). Experiment with 3D scene.

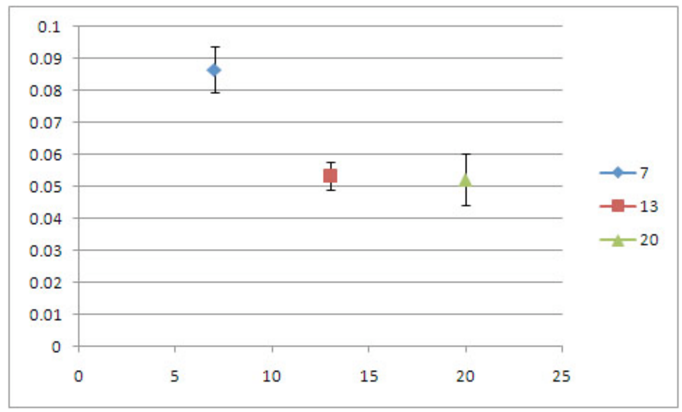

Figure 15: Comparison between high density cloud and medium density

The effect of density threshold leads us to propose visualization techniques that could allow an increase in density, without occlusion problems. Various interaction metaphors can be proposed:

- Appling transparent textures on the volumetric cloud points in order to allow perception of further visual information. This was implemented in our setup, and in a first informal test we observed that the stereoscopic fusion was difficult to achieve, probably because of too much similar visual stimuli.

- Adapting cloud density:

  Manually: We could suggest to the user controlling the density (through any interface : sliders, analog input) to provide an adaptive visualization interface. For example, a slider bar can be displayed and manipulated by the user during the pointing task.

  Automatically: Dynamic density of cloud point can be applied on different zones of a point clouds. For example, in high gradient areas the density is set to a high level otherwise a low density is given.

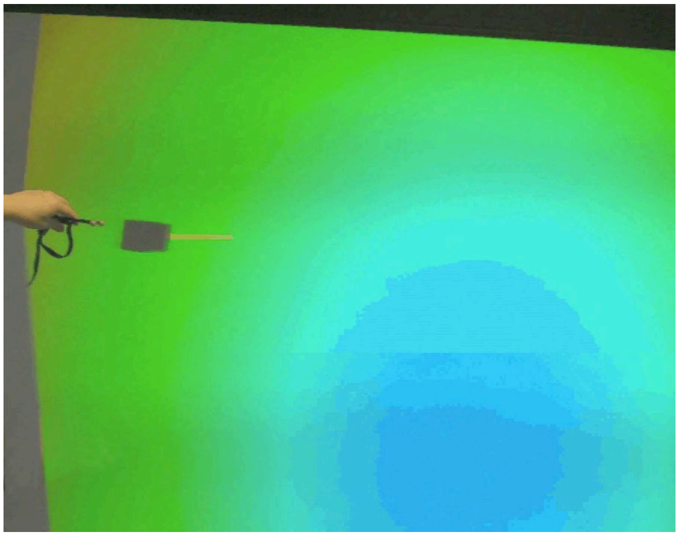

Figure 16: Cutting plane with dynamic texture.

- Increasing the use of movement parallax. This could be done by simply asking the user to move around more, to gain from a dynamic point of view through the head tracking system. This could also be done by providing the user with a displacement device (analog stick). Thus the user could easily get into the volume, gain from movement parallax, and reduce parallax by setting non relevant points behind the user.

- Reducing density in non relevant areas: we propose a 'Flashlight' metaphor for visual interaction. The principle is that the user would manually control a virtual flashlight, the cloud point density would be increased for points that are inside the flashlight cone volume. This would allow the user to actively choose high density areas.

6 CONCLUSION AND FUTURE WORK

In this work, we examined the consequences of density, point size and near clipping plane position differences for stereoscopic perception of a volumetric representation of temperatures using a point cloud technique. Our results of the present experiment shows that density and size of cloud point have a significant influence on the volumetric data perception. When the clipping plane position is close to the user, it significantly increases task completion time; this effect can be due to higher eye-strain from higher parallaxes.

We have observed an apparent threshold value of density, beyond this threshold the precision performance decreases. How could we push this limit in order to increase resolution without impeding correct visualization? One hypothesis is to increase the use of head tracking, for example: allow the user to get into the volume, which decreases parallax, and also reduces the number of objects between the user and the target objects. Another possibility would be to allow the user to actively choose high density areas by allowing him to reduce/increase the number of displayed points. This could be done using a flashlight technique, where the density would increase inside the flashlight cone.

We plan to compare these results to another visualization technique that we have implemented on the same setup. In this technique we propose to the user manipulating cutting planes. The planes have a dynamic texture whose color distribution depends on the temperature distribution in space. See Figure 16. The same high/low temperature pointing task will be proposed to a set of users. We plan to compare the ease of an extreme temperature search in volumetric temperature data between the two proposed techniques.

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