SIERA: The Seismic Information Extended Reality Analytics Tool

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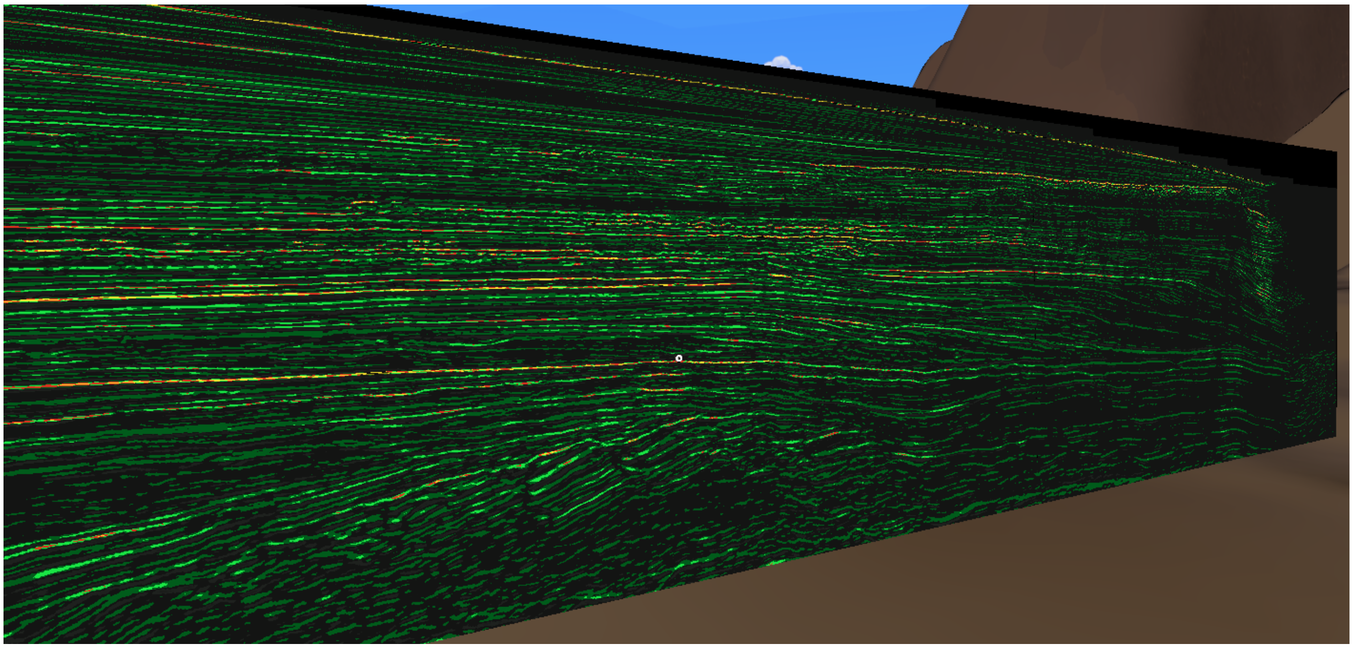

Figure 1: A seismic dataset visualized with SIERA in virtual reality as a three-dimensional volume.

ABSTRACT

Three-dimensional seismic data is notoriously challenging to visualize effectively and analyze efficiently due to its huge volumetric format and highly complex nature. This process becomes even more complicated when attempting to analyze machine learning results produced from seismic datasets and see how such results relate back to the original data. SIERA presents a solution to this problem through visualizing seismic data in an extended reality environment as highly customizable 3D data visualizations, and via physical movement, allow one to easily navigate these large, 3D information spaces effectively. This allows for a more immersive and intuitive way to interact with seismic data and machine learning results, providing an improved experience over conventional analytics tools.

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CCS CONCEPTS

• **Human-centered computing** → **Information visualization**; **Virtual reality**; **Visual analytics**.

KEYWORDS

Virtual Reality; Seismic Data; Immersive Analytics; Volumetric Rendering

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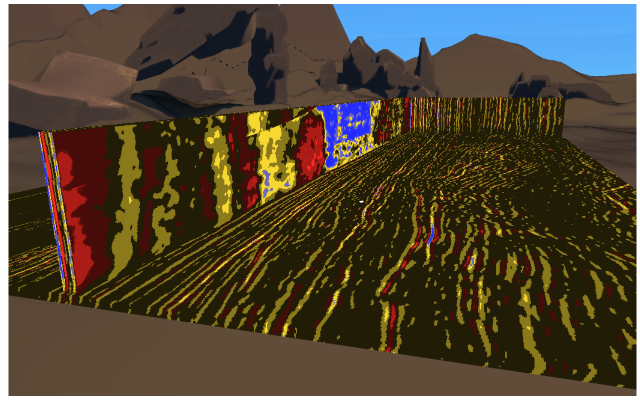
1 INTRODUCTION

This paper presents SIERA, an immersive analytics application helping geoscientists understand and visualize seismic data and the results of machine learning (ML) applied to seismic datasets[1]. Such datasets contain information on the sub-surface geological

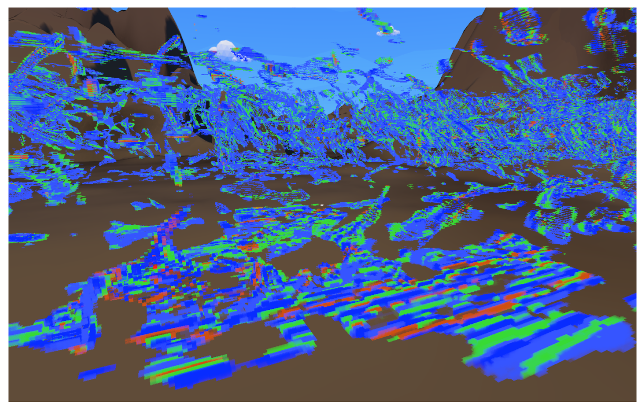
[1]Please note that using ML for detecting seismic fault lines is beyond the scope of this paper.

structure for a particular area and geophysical organizations collect them using a process known as reflective seismology. In a general sense, this technique uses seismic waves, which are sent down through the rock layers below the earth's surface. As these waves travel through the layers, they encounter boundaries between materials of different acoustic properties at which some of the waves reflect off the boundary back towards the surface and some refract through it to then continue propagating deeper. An array of receivers on the surface detect the reflected waves, at which point the time it takes each wave to travel from its source to the receivers is calculated. By knowing the travel times and velocities of the seismic waves, their paths can be roughly inferred. By combining these wave paths together, one is able to construct a three-dimensional representation of the sub-surface structure below a desired area which can then be analyzed by geoscientists. The resulting datasets are usually quite large, regularly being hundreds of gigabytes or many terabytes in size, due to the volume of data collected often being many kilometers in length along each dimension.

When needing to analyze these large seismic datasets, geoscientists use software tools to view the data with their trained eyes and make informed decisions concerning whether or not important features are present within the geologic structures. Such features could be fault lines, oil & gas deposits, or various geological anomalies for instance. These data visualization tools are vital to the seismic data interpretation process as they allow for efficient understanding and analysis of seismic data. Traditionally however, these tools all are limited by the fact that they use computer monitors to act as the interface between users and data, and thus rely on two-dimensional projections to display these large, three-dimensional datasets. As a result, one is limited in a number of ways when analyzing such 3D data using conventional tools, as the limited screen space of monitors and representation of 3D data using a 2D screen puts large constraints on how one can interact with seismic data effectively. In contrast, virtual reality has been shown to be a better interface for human interaction with 3D data in terms of both preference and intuitive interactability [3, 5]. Thus through the use of virtual reality, SIERA seeks to improve upon such tools by providing one with a virtual 3D environment in which to more naturally, efficiently, and effectively analyze 3D seismic data and higher-level ML results.



(a) Data visualization with colors chosen to correspond with specific data ranges, notably with red, yellow, and blue highlighting different important aspects of the data.



(b) Color-manipulated data volume with full-transparency applied to low ML certainty values, allowing one to view only the higher-certainty potential internal structures identified by ML.

Figure 2: Two examples of color and transparency manipulated data visualizations.

2 RELATED WORKS

The use of virtual reality to better understand the complex nature of sub-surface geological datasets is not unique to SIERA, as there are a few applications that have also previously used VR for such purposes. For instance, virtual reality has been prior used to visualize the structure of underground mines to identify seismic hazards more effectively [2]. To the best of our knowledge, the closest work to ours which uses VR to visualize seismic information is that by Santos et al. (2019) [4] whom also created a type of VR seismic data analytics tool. Although this software shares a similar base concept to ours, there is much that differs between the two. Notably, SIERA not only improves upon a number of aspects of Santos et al.'s prototype, but also provides entirely new functionality not present in their application. For instance, Santos et al. strictly chose to only visualize a few data slices at any given moment in order to appeal to a more traditional way of viewing 3D seismic data. SIERA on the other hand not only possesses this functionality, but also allows users to view the entire dataset as a whole or see data subsets that are not strictly slices but other shapes as well. Also by taking full advantage of volumetric rendering techniques, SIERA enables a user to remove unwanted data from view and see only that which they desire, a feature not present in Santos et al.'s prototype. In addition, SIERA can take full advantage of the space surrounding the user in virtual reality, able to fill the environment with numerous full-scale visualizations, which is a capability that Santos et al.'s prototype does not seem to possess. Lastly, the use of VR to visualize ML results has also been conducted previously, such as in the case of Douglas et al. [1]. What sets SIERA apart in this aspect is that there are no prior works to our knowledge which have done so for viewing and analyzing seismic ML results.

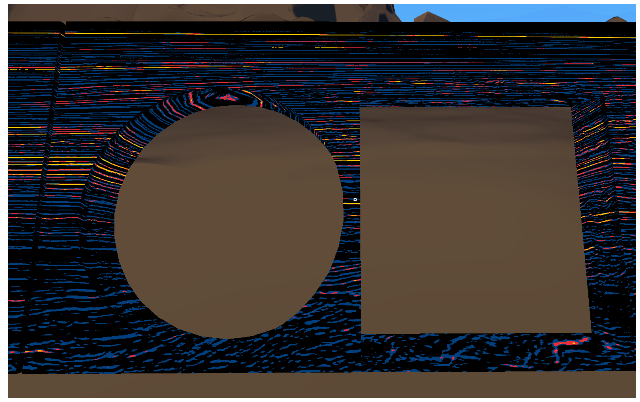
3 SIERA'S KEY FEATURES

3.1 Seismic Data Visualization

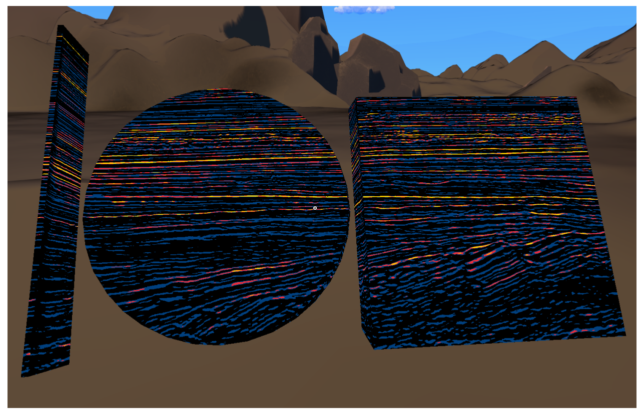
By utilizing volumetric rendering techniques, SIERA is able to take entire seismic datasets and visualize them in VR as interactive 3D volumes. These geospatial volumes are made up of numerous tiny voxels which each contain their own values for multiple assigned data variables, such as amplitude or ML certainty values. The number of voxels in a volume corresponds to the seismic data resolution, and since seismic datasets are usually quite large, it is often that case that each data volume contains many millions or billions of voxels. To visualize the data stored in these voxels, SIERA reads the values within each of them and applies end-user customizable color and transparency settings to then volumetrically render a unique, desired visualization of the dataset. An example of this can be seen in Figure 1. Several data volumes can be present in the same VR environment at a time. This is one of the main strengths of visualizing large datasets in virtual reality, as one is no longer restricted to the screen space of a monitor which limits one's ability to effectively view more than one data set at a time. In VR, one can take full advantage of the virtual free space around them and surround oneself with numerous large-scale visualizations however they see fit. This allows for the viewing and analysis of multiple datasets, or different aspects of the same data set, simultaneously within a single space. Users are also able to physically walk into these volumes and view the sub-surface structure from within, providing a more immersive way to view the data in close detail. Additionally, since 3D seismic data is now presented in true 3D, by simply looking at the data and moving around it one is able to more intuitively grasp its three-dimensional qualities when compared to conventional methods.

3.2 Data Highlighting & Filtering

Briefly mentioned above, a user is able to manipulate the color and transparency for each of the many voxels which together make up a visualization's volume. This allows for the ability to place emphasis on important aspects of the data by highlighting these with color (Figure 2a), and the efficient filtering out of data which one does not want to view through adjusting transparency (Figure 2b). As seen in Figure 2b, the transparency manipulation is especially useful for allowing one to view internal sub-surface structures which may not be apparent when viewing an opaque visualization in its entirety. This is all achieved by altering end-user customizable color and transparency gradients that are mapped to every voxel's corresponding data values and these two gradients can be manipulated differently for each visualization. As a result, one is able to simultaneously have multiple unique visualizations of the same data set present, each with its own particular combination of color and transparency effects to feature a different aspect of the data. This allows for the improved cross-comparison of data to better see how variables relate or possibly correlate with each other. Within the same data volume, the color gradient can be linked to one variable while the transparency gradient can be linked to another. This provides the ability to see in a single visualization if and how variables compare. For instance, with the color gradient mapped to an original dataset variable and the transparency gradient mapped to ML certainty values, a user is able see and directly compare how ML results relate back to aspects of the original data. Transparency can be set to be fully opaque when one does not wish to see through the external surface of a data volume, partially transparent when one wants to see through the outer surface, or fully transparent when one wishes to completely remove voxels with data values they do not desire to see, leaving behind only data important for the analysis at hand.



(a) Standard Rendering Mode



(b) Inverted Rendering Mode

Figure 3: Culling objects of a plane, sphere, and cube intersecting a volume using the two different rendering modes.

3.3 Cutting Out Unwanted Data

In order to efficiently cut away large portions of a visualization quickly, a user is able to spawn culling objects which when moved into a data volume remove from view the portion of the data intersecting with them. As shown in Figure 3a, these come in the form of cubes, spheres, or planes, and are especially useful for cutting into a visualization to analyze aspects of its interior with ease. These objects also can lock to one of their corresponding volume's three axes, so that when moved with one's hand, regardless of motion they only translate according to the portion of the movement vector parallel to the axis they are locked to. This provides ease of use when trying to move and place them exactly how one needs. As

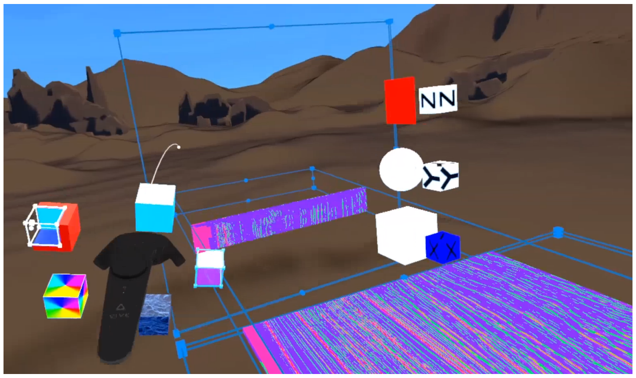


Figure 4: An example of a culling object being grabbed and moved within SIERA. Note the bounding boxes around the culling objects and data volume, as well as the hand-mounted menu in the bottom left corner.

many culling objects as one wants can be active in the environment at any moment, whose combined effects can together be used to view seismic data in ways previously not possible with traditional tools.

3.4 Viewing Desired Data Subsets

By switching into inverted rendering mode, the effect of culling objects is reversed such that instead of cutting into the data volumes, the rendered portion of the visualization is only that which intersects with the culling objects. As seen in Figure 3b, this provides users with the ability to focus on one or multiple subsets of the data volumes at a time without having to worry about the data outside these subsets getting in the way. When combined with the plane culling objects as in Figure 2a, this is especially useful to see one or multiple slices of a data volume at a time. Specifically, this exactly mimics the traditional functionality of viewing thin slices of data along a visualization's three axes, such as in Santos et al.'s prototype [4], with a few noteworthy added benefits in our case. First, one can increase the width of the slices through scaling to see multiple adjacent slices at once if desired. Secondly, as many slices as one wants can be present within the data visualization at any given moment, allowing for numerous parallel or perpendicular slices to be analyzed or compared against one another. Lastly these slices can be rotated to cut through a volume at any angle, providing one with access to views of data slices normally unable to be seen when using most conventional tools.

3.5 UI & Interactions

SIERA runs using the HTC VIVE and a controller-mounted menu allows for compact navigation between all of SIERA's features, including the spawning of data visualizations and culling objects. Once created, these can all be moved around the VR environment by grabbing them with one hand, as well as scaled and rotated by grabbing with two hands. For finer rotation and scaling, their toggleable bounding boxes can also be manipulated. An example of these features can be seen in Figure 4. This scaling also has the double-purpose of allowing users to zoom in or out of a chosen visualization at will, and then through movement, potentially place themselves inside of it. By taking advantage of the near unlimited space within a virtual environment, one is able to scale visualizations up to the size entire rooms if needed and then walk around to take a closer look at its finer details in a sense of scale simply not possible using traditional methods. Even if one does not have the real-world space to physically move around such large visualizations, they can still do so by way of a simple teleportation functionality which gives one the ability to move around the virtual environment without having to take a physical step. Menu panels are also able to be moved about the environment, allowing users to fully customize the layout of their surroundings to fit their needs and preferences when analyzing and interpreting seismic datasets.

4 CONCLUSION & FUTURE WORK

By taking full advantage of the virtual space a VR environment provides, SIERA enables users to analyze several large data volumes simultaneously and scale them to sizes impractical with traditional techniques for better analysis. Additionally, the incorporation of various volumetric rendering techniques allow for the creation of completely customizable and unique data visualizations through the use of voxel color & transparency manipulation, culling object intersection, and inverted volumetric rendering capabilities. Together, these provide SIERA users with a way to more intuitively and immersively interact with the three-dimensional nature of seismic data and ML results when compared to conventional software tools, providing a way to better analyze such data overall. Additionally, SIERA's functionality in many ways improves upon previous VR applications used to represent seismic data through a wider variety of data visualization options.

There are a number of ways in which SIERA could be improved further. One such way would be to give users the ability to mark or highlight regions of interest within a data volume with linked annotations so that analysts can attach notes directly to what they observe in the data visualizations. The ability for multiple users to collaborate within a VR environment and analyze the same seismic data set together would also be especially useful as it would enable professional analysts to combine their expertise and interpret seismic datasets together for more accurate and efficient results, regardless of the physical distance between them. We would also like to expand SIERA to run on augmented reality (AR) devices too in order to explore in what ways AR technologies can benefit the seismic data analysis process. Lastly, we intend to perform a user study with professional seismic data interpreters in order to evaluate SIERA further and receive feedback on how its capabilities could be enhanced in order to provide even more of an improved experience over traditional tools.

ACKNOWLEDGMENTS

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REFERENCES

[1] Nathan Douglas, Dianna Yim, Bilal Kartal, Pablo Hernandez-Leal, Frank Maurer, and Matthew E. Taylor. 2019. Towers of Saliency: A Reinforcement Learning Visualization Using Immersive Environments. In *Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces* (Daejeon, Republic of Korea) *(ISS '19)*. Association for Computing Machinery, New York, NY, USA, 339–342. https://doi.org/10.1145/3343055.3360747

[2] PK Kaiser, P Vasak, FT Suorineni, and D Thibodeau. 2005. New Dimensions in Seismic Data Interpretation with 3-D Virtual Reality Visualisation for Burst-Prone Mines. In *Proceedings of the Sixth International Symposium on Rockburst and Seismicity in Mines Proceedings* (Perth, 2005), Y Potvin and M Hudyma (Eds.). Australian Centre for Geomechanics, 33–45. https://doi.org/10.36487/ACG_repo/574_0.3

[3] O. Kwon, C. Muelder, K. Lee, and K. Ma. 2016. A Study of Layout, Rendering, and Interaction Methods for Immersive Graph Visualization. *IEEE Transactions on Visualization and Computer Graphics* 22, 7 (2016), 1802–1815.

[4] W. Santos, I. Chambers, E. Vital Brazil, and M. Moreno. 2019. Structuring and Inspecting 3D Anchors for Seismic Volume into Hyperknowledge Base in Virtual Reality. In *2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. 271–2713.

[5] W. Usher, P. Klacansky, F. Federer, P. Bremer, A. Knoll, J. Yarch, A. Angelucci, and V. Pascucci. 2018. A Virtual Reality Visualization Tool for Neuron Tracing. *IEEE Transactions on Visualization and Computer Graphics* 24, 1 (2018), 994–1003.