https://doi.org/10.2352/EI.2022.34.12.ERVR-187

Data Visualization of Crime Data using Immersive Virtual Reality

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Abstract

Visualization explores quantitative content of data with human intuition and plays an integral part in the data mining process. When the data is big there are different analysis methods and approaches used to find inherent patterns and relationships. However, sometimes there is a need to incorporate human in loop approach to find new patterns and relationships. Immersive virtual reality (VR) offers a human centric approach to visualize data by discovering new relationships that an existing algorithm cannot provide. This paper demonstrates the data visualization tool to visualize Baltimore crime data in immersive environment and non-immersive environment. This paper focuses on VR visualization tool design, development, and usability assessment. A pilot user study was conducted for the VR visualization tool based on the system usability scale. The study results show that the crime data visualization tool is relatively easy to use, and that the application can be considered as a storyteller with removing the noise from the data and highlighting the usefulness of the information.

1. Introduction

Immersive data analytics lies at the intersection of data science, virtual reality, 3D interfaces and user interaction. It allows data insights from visualization, display and interaction techniques by incorporating human ability to analyze and make use of heterogeneous data. We are using immersive virtual reality to provide a 3D representation of the information collected and to better understand how this data can be used to mitigate future crimes. The crime rates in the Baltimore County have been increasing a lot lately and our research is trying to perceive the gathered statistics to communicate a message supported by the data. Our study also suggests that the users feel immersed in the statistics provided by the immersive virtual reality that makes the users more satisfied and drive towards achieving the goals. Data driven decision making is the process of using data to inform your decision-making process and validate a course of action before committing to it [1]. In most of the studies more than half of the Americans rely on their gut to decide what to believe and when they are confronted with evidence that speaks the contrary [1]. Many security officers have raised their concerns over the gut feeling of general public, often individuals end up choosing an unsafe route leading to higher criminal activities.

Decision making is largely dependent on data, which can be so overwhelming at times that just the volume of it can't be comprehended without layers of abstraction, such as a visual visualization [2]. Data visualization is extremely effective in communicating the criminal data to the public, police, and security officers. Visualizing data is one thing but being able to see the data in a 3D immersive environment can elevate the experience further by providing options to drill down into charts and graphs, changing data interactively based on region or crime categories.

In recent years, there have been numerous studies on the prediction of criminal occurrences. In 2020, the FBI estimated crime statistics for the nation are based on data received from 15,875 of 18,623 law enforcement agencies in the country that year [3]. The growing number of crimes is the major concern for the police force, security agencies and the general public. Police officers are in general responsible for maintaining law and order situation. Crime analysis is the activity of aggregating all the crime reports to generate a single comprehensive report of all crimes, which helps in decision-making and controlling crimes [4]. Visualizing this data in an immersive environment can help in better understanding the trends and predictive modelling of the gathered information.

The immersive virtual environment creates an environment which looks realistic, and the users can feel it as close to real as possible. The immersive environment also helps in the visualization of the data especially when the data is huge. With immersive environment the user is expected to understand the pain areas better and perceive the charts and graphs better. Immersive environment is the latest and greatest way to interact with the virtual environment created. It also helps in we conceive new approaches in our relationship with reality.

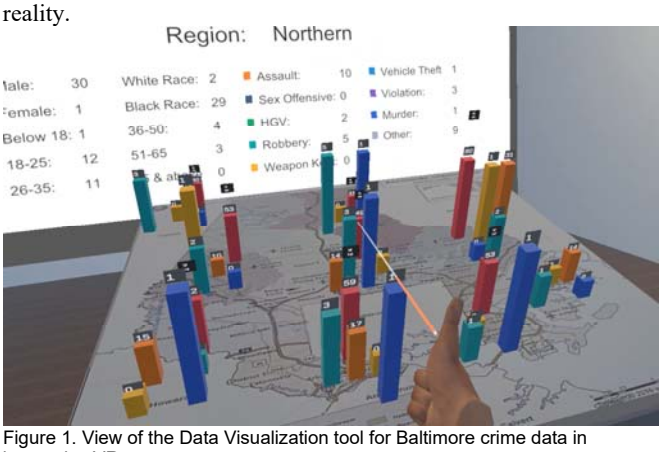

Figure 1. View of the Data Visualization tool for Baltimore crime data in immersive VR

In our application security officers can see in real-time which regions are in more need of security and which regions need more supervision and or patrolling. Figure 1 below shows how the region selection helps in filtering data for a particular region and showcases the records for that region. Our research focuses on applying virtual reality interaction for big data visualization by including human cognitive limitations. We have incorporated 3D interaction techniques over geographical information to enhance situational

awareness as shown in figure 1. As shown in Figure 2, the security officers have the capability to select the type of charges.

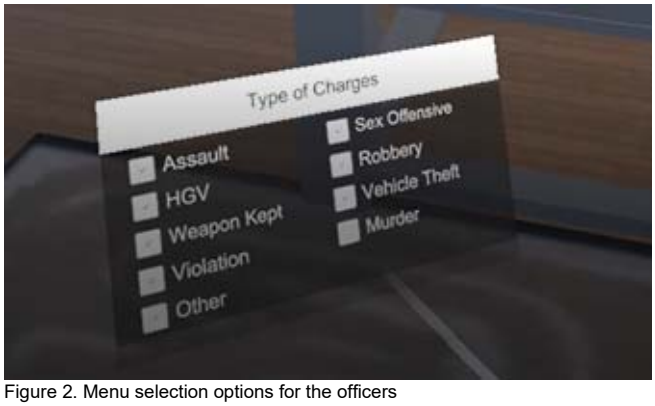

Figure 2. Menu selection options for the officers

The data visualization tool is developed using the Unity gaming engine. It provides the capability to toggle on/off the different variables related to the crime data on top of the Baltimore county map. The map displays The various types of charge are:

- Assault
- HGV
- Weapon Kept
- Violation
- Sex Offensive
- Robbery
- Vehicle Theft
- Murder
- Other

For all variables, checkboxes are implemented as shown in figure 2. These checkboxes provide the capability to enable and disable the bars on the map. This provides the user a way to compare data for the different county's. Our goal is to provide an understanding of crime data for different county's for decision making. The user is also able to select a state and view its related information in detail.

The rest of the paper is organized as follows: Section 2 discusses the related work in data visualization as well immersive VR; Section 3 details the system architecture of the data visualization tool; Section 4 describes the implementation of the application in three phases; Section 5 describes the results of the user study and evaluation of the 3D data visualization tool, and Section 6 discusses the drawn conclusions and proposed future work. Finally, Section 5 states acknowledgments.

2. Related Work

Predictive analysis according to Nyce [5] is a statistical technique used to develop models that predict future events. The predictive models derived using scores are measured on features which are extracted using accuracy, precision, and recall. Crime data provides us a lot of insight on the data points like race, sex, demographics etc. Yerpude et. al [6] have discussed that analyzing this data not only helps in recognizing a feature responsible for high crime rate but also helps in taking necessary actions for prevention of crimes. Growing amount of criminal data gives rise to numerous problems like data storage, warehousing, and analysis [7].

Many techniques have been brought to light which help in solving problem of extracting knowledge from the vast data available using different algorithms. One such application is that of finding knowledge of criminal behavior from its historical data by studying the frequency of occurring incidents [7]. P.Thongtae [7] gave a comprehensive survey of effective methods on data mining for crime data analysis out of which one was 'Regional Crime Analysis Program' that is used to turn data into knowledge using data fusion. Data fusion manages, fuses, and interprets information from different sources and overcomes confusion from cluttered backgrounds.

Paik [8] has explained very logically that one important goal of computer science is complete simulation of human which has been achieved through cloud computing, big data and artificial intelligence with machine learning. Process of situation awareness consists of (1) Perception to obtain necessary information (2) Comprehension of situation to identify facts for capturing situation (3) Projection to infer proper reaction to the situation. It's the situational awareness that help perceive the data, comprehend the situation and help project the data in the usable format.

Sharma et al. [9-12] have described a data visualization tool using Unity 3D and Maptitude GIS for visualization of COVID-19 data and crime data in Baltimore. Their study shows the factors to be influential in a person's susceptibility include neighborhood and physical environment, housing, occupation, education, income, and wealth gaps. They have discussed the need for human-centric situational awareness and visualization that are needed for analyzing the big data in an efficient way. Sharma et al. [13-15] have also presented data visualization for location based navigation in multilevel spaces by generating augmented reality instructional visualizations with contextualized communication of evacuation plans. HoloLens has also been used for creating situational awareness in indoor evacuation environments [16-18].

Livnat et. al [19] have discussed that situational awareness is the continuous extraction of environmental information, its integration with previous knowledge to form a coherent mental picture, and the use of that picture in anticipating future events. Legg [20] stresses that situation awareness is often described as the perception and comprehension of the current situation, and the projection of future status. The situational awareness is what helps in better perception of the general public and security officers. To learn more about the various techniques to visualize data we referred to an interesting article by Renato et. al [21] where they mentioned that to achieve the most understandable and accurate display of information, a study on the available techniques of data visualization for real-time information must be made.

3. System Architecture

3.1 Visualization of Crime Data

Visualizing data in 2D doesn't project the data as well as in a 3D environment. Three-dimensional data helps in the better understanding of not only the statistics but also the trends of the crime data. With 3D visualization the statistical data is much clearer gives a clearer picture of the data and the flow. In the visualization tool we provide the users the capability to select and filter the data dynamically. Users can select the type of charge first.

Once the user selects the type of charge the data from the crime data is filtered and displayed based on the region selected. Users can see the count based on the charge. Also, they can visually see the crime statistics based on the region. We have used Unity 3D, Oculus and C# scripting for our project. With this we were able to create a robust architecture which was able to handle multiple json data requests as well as parse json data in runtime. The architecture as shown in Figure 3 below shows the architecture for our application.

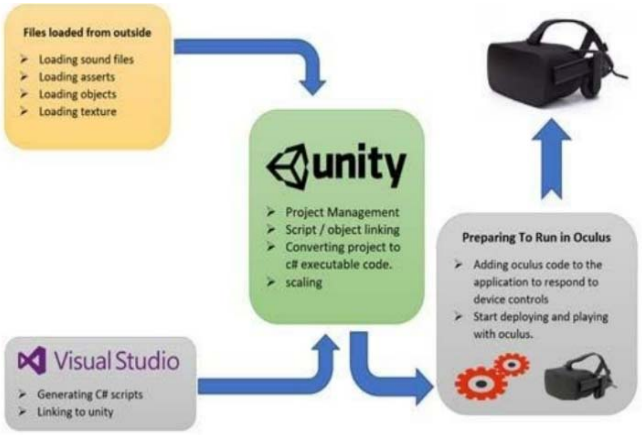

Figure 3. System Architecture

3.2 GUI and Interactions

The GUI of our tool was designed keeping in mind the ease and usability to all users especially for security forces. Our tools UI consists of various controls, but they differ based on the environment.

1) Immersive environment:

The user gets the feel of walking around the room with Baltimore County map on display and the filter in the hand. They have the flexibility to click the buttons and checkboxes in the menu or the filters using laser pointers. In the immersive environment the user is given the option to use the laser beam with the handheld controls. The user can use the handheld device to point at the menu option, select an area in the map, click on the bar graph and that would result in displaying the selected data.

The user can navigate in an immersive environment by using the joystick attached in the handheld device or by point the laser beam at a location and clicking it. The laser beam can even help in highlighting the menu controls and it provides and easier interaction compared to the standard keyboard controls.

2) Non-Immersive Environment and mobile environment

For a non-immersive and mobile environment, the user can also walk through the room with the map on display however for navigating the controls used are WASD on keyboard. The non-immersive environment provides user the opportunity to navigate using the keyboard and the mouse. For mobiles it provides the flexibility to zoom in and out.

In our visualization tool Unity 3D acts as Project Management layer. It pulls the data from Baltimore County site, parses the json using Visual Studio C# scripts. Returns the data to the user in Unity. Besides loading the data from json Unity also loads the assets, the 3D model created using SketchUp that contains all the structures and objects. Unity 3D is designed such that it can manage when to pull the data, customize the scripts and render data per the requirements. Once the data is ready it is sent to Oculus to provide users with the controls to see and select various options.

The major challenge we faced in this visualization tool was reading the json file data. The data sent was large and segregating it into regions took a while. Also, we added various filters and to filter the json data per the user needs. The scripting involved labelling all the bars, color coding them and adding a count to them. Based on the regions, counts, assaults and crime the data was further segregated down for easy rendering in the UI. For the user the data flow was smooth without major hiccups. We have integrated Oculus Rift S virtual reality HMDs (Head-mounted Display). It allows for immersive 3D visualization by exploring how data extracted from real-time updated API can be embedded on top of geographical maps for visual analytics. The visualization tool gives an enriched immersive experience to the user.

4. Data Visualization Tool

The implementation for our application was done in three phases. The first one was the modelling phase, the second being the Scripting phase and third one was hardware integration phase.

4.1 Phase 1: Modeling

Phase 1 of the data visualization tool consisted of modeling the 3 D environment using 3Ds max and google sketch up. The environment was modeled to scale and imported real-time textures. After modeling the 3D environment, it was exported to unity 3D gaming engine. We added various elements like the panel for adding filters and screen to show the map. First person controller was added for the camera and navigation view. The meeting room was designed using various materials like coffee table, chairs, lampshades, plants, cylinders for lighting to give a very realistic feel to the room. Many rectangles were aligned to give the looks of curtains and partitions. Figure 4 below shows the various UI elements in the data visualization tool.

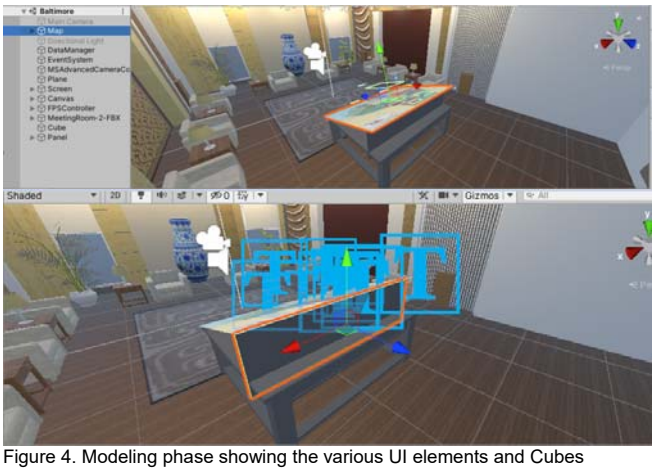

Figure 4. Modeling phase showing the various UI elements and Cubes showing bar graph placeholder

We used the readily available assets and added those to our application. We ensured that the various aspects like scaling, look and feel from user perspective were considered.

4.2 Phase 2: Scripting

In the second scripting phase we connected the modelling design sketch with the custom scripting. We wrote custom script to read the json data. It was handled in the Data Manager element in Unity. The country data bar script describes how the country data is processed and how the data is read from the Baltimore County site as shown in Figure 5. We also added custom codes for the UI popups, graph rendering and highlighting regions. RayCast manager in Unity was used to associate the script to the various bar graph parameters. For Ex: the text representing the total positive cases is AgeValue and that can be mapped to the Positive value in the script. Similarly Recover value is associated with Recover value text. This script is the heart of the application as it let us map the parameters seen on screen with the parameters formatted in the json data. It provides the mapping of onscreen fields to the backend scripts.

```
[SerializeField]
DataManager m_DataManager;

public static CountyDataBar instance = null;


public List<CountyData> countyData = new List<CountyData>();

[SerializeField]
List<int> arrestArr;

private void Awake()
{
    if (instance == null) instance = this;
}
// Start is called before the first frame update
public void  _Start()
{

    for (int j = 0; j < countyData.Count; j++)
    {
        for (int i = 0; i < m_DataManager.m_Arrest.Length; i++)
        {

            if (m_DataManager.m_Arrest[i].district == countyData[j].name.ToString())
            {
                countyData[j].arrest++;
            }
```

Figure 5. 3D data visualization in an immersive environment

4.3 Phase 3: Hardware Integration (Oculus Rift S)

The third phase involves the hardware integration. We have integrated Oculus Rift S in the Unity3D code. We have presented bar graphs with oculus controller to combine the bar chart visualization with a zooming feature that allows users to view the details more effectively. The Oculus Touch headset (refer figure 6) allows the users to navigate and experience the environment with full immersion. Oculus Touch controllers also give haptic feedback to the user when using objects such as laser pointer.

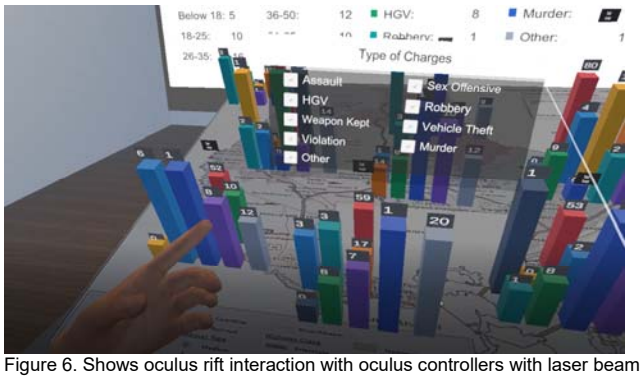

Figure 6. Shows oculus rift interaction with oculus controllers with laser beam

5. Evaluation and Results

We conducted a system usability scale (SUS) user study to evaluate how effective our proposed solution is. We created a survey questionnaire to evaluate the effectiveness of the tool and to get user feedback.

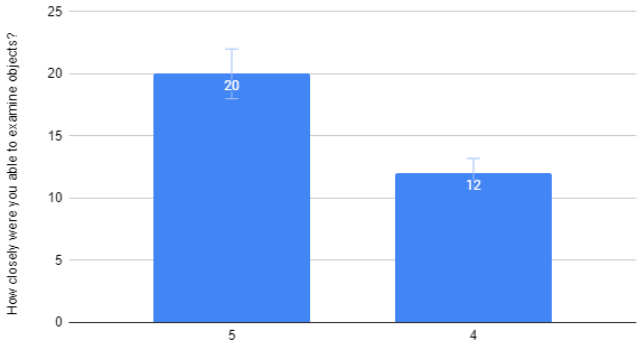

Figure 7. Shows how closely were the users able to examine objects

The user study incorporated 7 participants out of which everyone was proficient in using the immersive environment through Oculus Rift S. Figure 7 shows that 57.1% of users were able to closely examine the objects in the immersive environment as compared to non-immersive environment. The users were also asked how responsive was the environment to actions that you initiated (or performed). Figure 8 shows that 71.4% of the users agreed that the environment was responsive to the actions initiated.

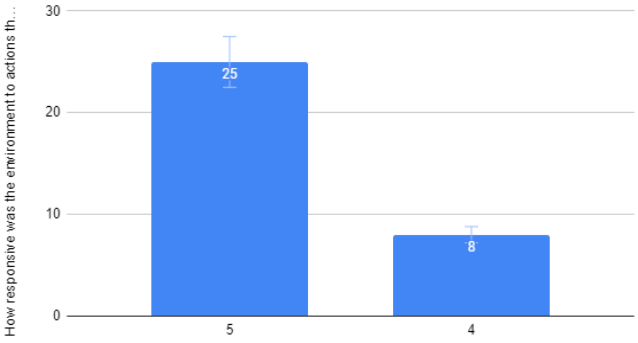

Figure 8. Shows how responsive was the environment to actions initiated (or performed) in the environment

5. Conclusions

Overall, our VR data visualization tool was perceived as satisfying and successful in visualizing the crime data and gave insights during the comparison of data with different county's. VR helps in engaging the user for more effective data analysis with more human-in loop interaction. The 3D representation of the data helped users in understanding the crime statistics better. The study results show that the crime data visualization tool was relatively easy to use, and that the application can be considered as a storyteller with removing the noise from the data and highlighting the useful information. We intent to add more features in future like data mining activities and predictive modeling which would add a lot of value to our initial data visualization effort.

The benefits of our proposed work include providing a data visualization tool for immersive visualization and visual analysis. We also suggest key features that immersive analytics can provide with situational awareness and in loop human intervention for decision making. We evaluated visualization tool with participants by incorporating a more fine-grained analysis of insights for ease of interaction, examine objects, interactions, responsiveness, and adjustment to virtual environment. We are also interested in

extending our VR data visualization tool to enable collaborative, multi-user data exploration for analytics tasks.

Acknowledgments

This work is funded in part by the NSF award 1923986, NSF award 2131116, NSF award 2022981, and NSF Award: 2026412. The authors will also acknowledge Mr. Sri Teja Bodempudi for his help in building the visualization tool.

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