SPATIAL DATA VISUALIZATION IN COLLABORATIVE IVR

Ondřej Kvarda, Čeněk Šašinka, Zdeněk Stachoň

MSc. Ondřej Kvarda, Masaryk Univesity, Faculty of Science, Department of Geography, Kotlářská 2, 611 37, Brno, Czech Republic, kvarda.ondrej@mail.muni.cz;

Assoc. Prof. Čeněk Šašinka, Ph.D., Masaryk Univesity, Department of Information and Library Studies, Faculty of Arts, Arna Nováka 1, 602 00, Brno, Czech Republic, cenek.sasinka@mail.muni.cz

Assoc. Prof. Zdeněk Stachoň Ph.D., Masaryk Univesity, Department of Information and Library Studies, Faculty of Arts, Arna Nováka 1, 602 00, Brno, Czech Republic, and Department of Geography Faculty of Science, Kotlářská 2, 611 37, Brno, Czech Republic, zstachon@geogr.muni.cz

Abstract
This research explores the transition of cartographic visualization from 2D to immersive virtual reality (iVR), enhancing 3D visualization capabilities. With advancements in computer technology and GIS, cartography adopted the third dimension but was limited by 2D interfaces such as monitors and keyboards. iVR technology offers a true 3D experience with intuitive interactions like hand gestures, enabling a deeper perception of spatial data through "six degrees of freedom." Despite its potential, iVR poses challenges that include user adaptation and physical side effects. This study presents a platform developed in Unity to test 3D cartographic visualizations in iVR, focusing on dynamic user interaction and analysis of geodata. A pilot study evaluates these methods against traditional approaches, aiming to enhance empirical research and design in immersive geographic environments.

Keywords: *Immersive Virtual Reality, Spatial Data Visualization*

INTRODUCTION

For most of its history as a science, Cartography has been a domain of mainly planar visualizations restricted to only two dimensions. The advent of the third dimension into cartography can be tracked to the second half of the 20th century with the emergence of computers and geographic information systems (GIS). However, even these 3D representations are limited by the technology used to mediate them to the user. The 3D data are visualized onto 2D computer monitors and are being interacted with via keyboard and mouse (or similar devices). This non-immersive way of visualization and interaction in turn limits the possibilities and potential of such 3D visualization and leaves much to be desired in terms of perception and cognition. In this sense, the fairly new and emerging technology of immersive virtual reality (iVR) can be employed to surpass the limitations of such visualization methods as it offers the user the possibility to immerse himself and become part of the true 3D visualization itself and interact with it in a more natural and less limited manner (e.g., via hand controllers, hand gestures or movement of his whole body) (Medyńska-Gulij et al., 2021). The main advantage of this technology, besides the fidelity of the 3D visualization, is the ability to mediate the concept of “six degrees of freedom” (the capability to track lateral as well as rotational movements in a real environment and transmit them into the virtual environment) which can change the perspective through which we assess the visual stimuli and therefore can influence the way we perceive, compare, and discern particular objects from one another, which is crucial for cartographic visualization. There are, of course, also possible downsides of using this technology, mainly regarding the technological aptitude of users (i.e., how fast, or if even, can they adapt to this new technology interface), physical well-being of users (VR is known to cause nausea in some users) and technological feasibility of the proposed solution (dependent mainly on the processing power of the hardware and the possibilities of interaction). In order to fully utilize the advantages of iVR, one must design the solution with regard to the possibilities and limitations of the chosen hardware and adapt the whole interface/visualization best to reflect the needs and experience of the user. Although the concepts of iVR are nothing new in cartography (Bodum, 2005; Yucel, Selcuk, 2007), this “new frontier” has not seen much research in this regard and is still insufficiently covered and worthy of more attention. Present studies that combine cartography and iVR focus mainly on issues related to cartographic visualization and interface (Yang et al., 2018; Satriadi et al., 2020; Ghaemi et al., 2022), interaction (Huang, Chen, 2018; Dong et al., 2020, Newbury et al., 2021), or cartographic visualization of spatial data (Yang et al., 2019; Quach, Jenny, 2020; Yang et al., 2021).

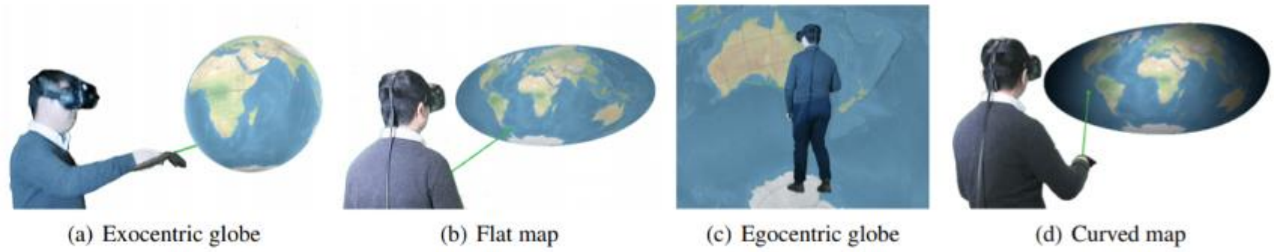

Figure 1. Proposed approaches to Cartographic Visualization in iVE (Yang et al, 2018)

As this new approach to mediating cartographic visualization in iVR hasn't seen much coverage yet, it is imperative to focus not only on the design of the visualizations themselves but mainly on thorough empirical research that will serve as a baseline for those designs. User studies can be helpful in this regard as they allow for flexible testing of different design solutions on a certain number of users with various output data.

TECHNOLOGY

To carry out such studies, one needs to prepare the technological solution that allows for user testing (i.e. that has a specific testing scenario with tasks and logs users' interaction/behavior throughout the testing) as well as appropriate research and analysis methods (be it quantitative or qualitative, or better yet, both combined) that will be employed to conduct and afterward evaluate the study.

The presented technological solution is designed as a collaborative platform for testing various 3D cartographic multivariate visualization methods and interactions with the cartographic interface in iVR. Its collaborative and network component is based on the open-source eDIVE software platform for the game engine Unity (Šašinka et al., 2021; Šašinka et al., 2023; eDIVE, 2023) which is an outcome of applied research that enables conducting multidisciplinary research in a collaborative immersive virtual environment in various research areas. The VR hardware of choice is VR HMD Pico Neo 3 Pro Eye with integrated eye-tracking from Tobii from the Laboratory of Virtual Geographic Environments (VGE lab). (See figure 2.)

Figure 2. Pico Neo 3 Pro Eye (left) and Oculus Quest 2 used in the VGE laboratory

DATA

The central part of the immersive virtual cartographic visualization is a virtual map that can be fed with georeferenced polygonal, linear, or point data in the GeoJSON data format (with defined WGS 84 / Web Mercator projected coordinate system coordinates) and display this data in the given geographical extent as 3D objects in the virtual scene. This makes it easy to switch between various areas that one would like to display. The user is then free to manipulate the map in several manners. Users can scale it, rotate it, move it, or switch the position of the map to be directly underneath him (as if he were standing on it); all while being able to move about the virtual environment via teleporting. There's also the option to upload multivariate data (also in the GeoJSON data format) and automatically display it in two different multivariate visualization methods in georeferenced locations on the map. User can then switch between these visualizations on his own accord. The capability to highlight and select a certain area of interest with displayed multivariate data is also implemented for the sake of testing different visualizations.

ACTIONS LOGGING

Crucial for conducting and evaluating certain user studies are logging capabilities that allow for data collection throughout the entire experiment. When it comes to logging events (interaction with the interface and the map, i.e. manipulating the map, selecting features, etc.), position (coordinates of the users' position), and other measurements, a system of logging algorithms is implemented that logs these throughout the whole runtime. Also implemented is simple object-based eye-tracking that tracks on which object, when, and for how long was the user fixated. All these measurements are logged into CSV files and stored in the memory of the headset. The users can therefore inspect the cartographic visualization, manipulate it, and interpret it all the while being tracked and their actions recorded.

PILOT STUDY

The current concept of a pilot study conducted using this platform concerns the evaluation of the suitability of different 3D multivariate cartographic visualization methods in iVR between themselves and also against the same methods used in non-immersive desktop visualizations. The user will be presented with a map visualization where different regions have different values of multivariate variables and he will be prompted to select the region which corresponds to set requirements (e.g., low phenomenon 1 and high phenomenon 2). Two bivariate visualizations (bar charts and chernoff faces – see figure 4) differing in separability were selected. The study is designed as between subject and focused primarily on university students. The design starts with the informal conset, and continues with sociodemographics questionnaire, eyetracking calibration (figure 3), training task and bivariate visualizatiuon tasks.

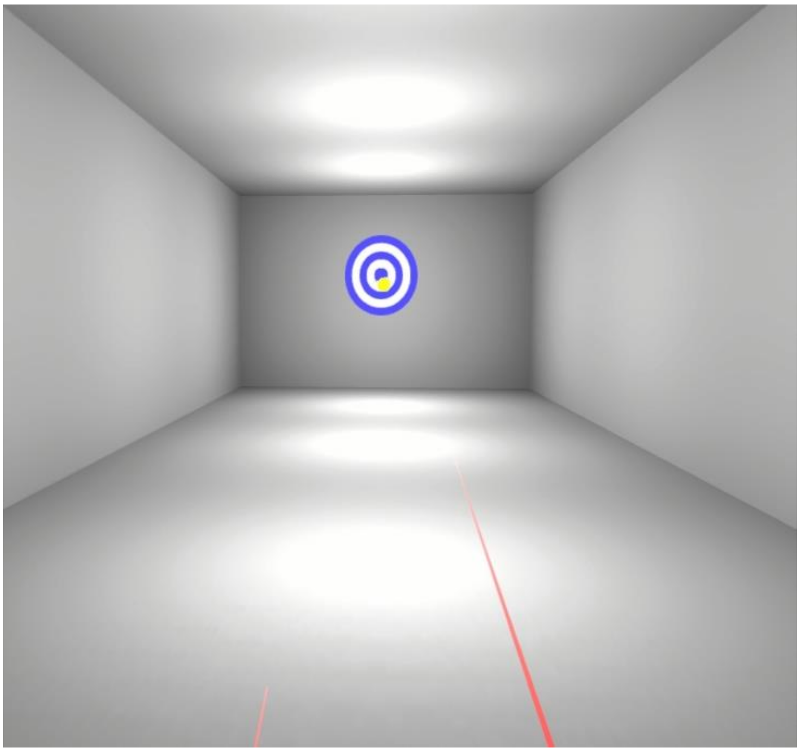

Figure 3. Eyetracking calibration

After going through multiple iterations, the correctness and response speed will be evaluated across different visualization methods and also the immersive versus non-immersive visualizations. Additional variables, like eye-tracking, positional data, or interaction events will be evaluated as well to possibly identify specifics of interaction with mainly the iVR interface that could aid the design of a more suitable interface and interaction approaches. The results of this study should set the baseline for subsequent research regarding the problematics of 3D cartographic visualization and interaction with virtual cartographic interfaces in iVR.

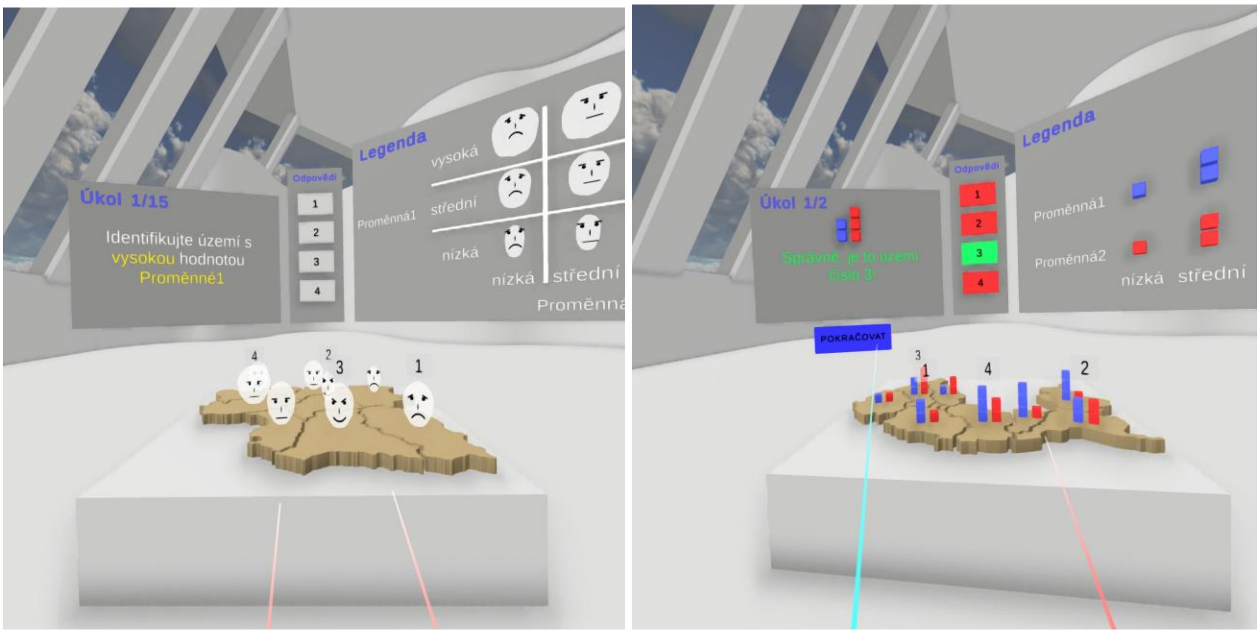

Figure 4. Example of used bivariate visualizations (Chernoff faces – left, and Bar charts)

The study is still in progress at this moment (data collection is currently ongoing). The results will be ready to be presented at the ICCGIS conference.

CONCLUSIONS

The study concludes that immersive virtual geographic environmets offers a significant enhancement over traditional 2D and non-immersive 3D cartographic visualization methods by providing a deeper, more intuitive interaction and perception of spatial data. The use of iVR technology, particularly the eDIVE software on the Unity engine and VR HMD Pico Neo 3 Pro Eye, allows for advanced user interaction and visualization, including manipulation of georeferenced data displayed as 3D objects within a virtual environment. The pilot study collected the correctness, speed respenses, actions of users and also the eyetracking data underlining the importance of iVR's "six degrees of freedom" in providing a realistic and engaging user experience.

Crucially, the study identifies challenges such as user adaptation to new interfaces and potential physical side effects like nausea. Nevertheless, it emphasizes the necessity for ongoing research and development, particularly in designing interfaces that optimize user interaction and data interpretation. The logging capabilities integrated into the system, including eye-tracking and interaction event recording, are essential for gathering data to refine and enhance iVR cartographic visualizations further.

Overall, the preliminary findings suggest that while iVR presents several challenges, its benefits in cartographic visualization and the potential for detailed empirical research make it a promising area for future exploration and application in various fields.

In the future, we plan to implement automatic multivariate visualization generation for more multivariate visualization methods, or interaction via hand gestures. Our goal is to in the end create a multifunctional collaborative platform for testing 3D cartographic visualizations and interaction with cartographic visualization in iVR with the ability to automatically log all the necessary measurements needed to analyze and evaluate said cartographic visualizations.

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BIOGRAPHY

MSc. Ondřej KVARDA

Ondřej Kvarda is a PHD student on the Department of Geography, Masaryk University, Czech Republic. He focuses mainly on the cartographic visualization within immersive Virtual Environments (iVEs).

Assoc. prof. Čeněk ŠAŠINKA, Ph.D.

Čeněk Šašinka works as an associate professor at the Department of Information and Library Studies, Masaryk University. He is currently a principal investigator in several research projects. He focuses mainly on the cognitive processing of graphically coded information and research methodology.

Assoc. Profeossor Zdeněk STACHOŇ, Ph.D.

Zdeněk Stachoň works as an associate professor on the Department of Geography, Masaryk University, Czech Republic. He focuses mainly on the user studies on Cartographic Visualization dealing with principles of map design, cognitive aspects of cartographic visualization, and geographic support of decision making. He is a member of the Czech Cartographic and Geographic societies, vice-chair of the UX commission of International Cartographic Association.