Santos-Torres, A., Zarraonandia, T., Díaz, P. et al. An empirical comparison of interaction styles for map interfaces in immersive virtual environments. *Multimed Tools Appl* 79, 35717–35738 (2020).

DOI: [10.1007/s11042-020-08709-9](https://doi.org/10.1007/s11042-020-08709-9)

An empirical comparison of interaction styles for map interfaces in immersive virtual environments

Andrés Santos-Torres[1] · Telmo Zarraonandia[1] · Paloma Díaz[1] · Teresa Onorati[1] · Ignacio Aedo[1]

Abstract

Geographical Information Systems (GIS) can be visualized using immersive technologies like Virtual Reality (VR). Before using this kind of technologies it is required to explore which interactions are affordable, efficient and satisfactory from the users' point of view. The purpose of this work is to provide insight on how to design efficient and natural interaction on GIS VR interfaces. This study presents a within-subjects comparative study that assesses the usability and performance of two popular interaction strategies: body-based interaction and device based interaction. In body-based interaction, participants use their hands and head orientation to control the VR map. In the second case, users interact with the Oculus Touch controller. Thirty two users participated in an experiment whose results suggest that interacting with the controller improves performance of the selection task, in terms of time spent and error rate. Also, the results show a preference of users for the controller in terms of perceived usability.

Keywords Map interfaces · Interaction · Immersive virtual reality

✉ Andrés Santos-Torres
andsanto@inf.uc3m.es

Telmo Zarraonandia
tzarraon@inf.uc3m.es

Paloma Díaz
pdp@inf.uc3m.es

Teresa Onorati
tonorati@inf.uc3m.es

Ignacio Aedo
aedo@ia.uc3m.es

[1] Department of Computer Science, Universidad Carlos III de Madrid, Madrid, Spain

1 Introduction

GIS-based maps are used to help understanding, interpreting and manipulating any location-related information. The geo-enabled data this type of systems provides are used to support many decision-making processes in the context of environmental impact analysis, emergency management, or the evaluation of interventions and policies applied in specific geographical areas, for example. Traditionally, users visualize and interact with the GIS-based maps using standard desktop computers, interactive tablets or large screens, but the reduction of the cost of the Virtual Reality (VR henceforth) equipment has opened up new opportunities to use this technology to display and explore the data through immersive data visualizations.

The scope of this work falls into the broader area of Immersive Analytics, an emerging research topic that explores the use of immersive technology for creating interactive data visualizations that facilitate the analytical reasoning and decision support [10]. Immersive environments are expected to provide a better perception of the data-space geometry and facilitate representing multi-dimensional information [12]. Also, the immersive displays provide the user with a wider field of vision than traditional laptop and desktop computer's screens [21], allowing to visualize more data at once. In addition, they could support collaborative tasks through telepresence [4]. These features have already been exploited in the creation of immersive interactive visualizations of neural structures [38], protein molecules [2] or multidimensional data [11].

However, research on all the relevant factors affecting the virtual selection and manipulation experience in different contexts is still needed [22]. In the case of VR GIS interfaces this is crucial, as due the nature of the context they are normally used, providing an effective interaction solution that allows to rapidly operate the system is paramount. In the case of a GIS interface, the interaction technique implemented should support the manipulation of the data representation by means of five basic operations: zoom, pan, buffer, display and the location selection of geo-spatial data [30]. As with any other interactive system, the interaction possibilities of the devices used will impact on the productivity of the task, the user engagement and, in general, the user experience. Body-centred interactions that match the physical and virtual body movements contribute to maintaining the feeling of being present in the virtual environment [32], and such sense of presence increases engagement. Moreover, body-based interactions make it possible to explore large information spaces without moving or using any additional interaction device [9]. However, it is no clear yet whether body-centred interaction is better than using the controllers offered by most commercial VR headsets, whose interaction capabilities might be more evident for many users, specially for those familiar with the gamepads use for gaming.

This work is an extension of our initial study [31] presented on the conference Interacción 2018. In particular, in this extended version not only the literature review has been expanded to cover all the related works but also the experiment was improved with a bigger number of participants to confirm our initial findings. The aim of the research is to investigate how immersive map-based interaction (user input) might be influenced by the performance and usability of these two popular interaction strategies: body-based interaction and device-based interaction. To address this research we designed and implemented a immersive interface for map visualization using a Head Mounted Display (HDM) with the two interaction strategies. In the first case, the user interacts with the environment using her own body (hands and head). In the second case, the interaction is mediated through a device (the Oculus Touch). The results of a study with 32 participants suggest that controlling the map using a control device can improve the performance of the selection task, in terms of time and error rate. Also, the user' satisfaction responses for system usability favored this interaction strategy.

The rest of the paper is organized as follows. Section 2 presents some related works. Section 3 presents the research questions and hypothesis of this work. Section 4 introduces the VR environment developed for the study. Section 5 describes the experiment of this study. Section 6 presents the results of the study. In Section 7 we discuss the results, and in Section 8 we outline the limitations and future lines of the work. Finally, in the last section of the paper we present some conclusions.

2 Related work

The related research comes from the areas of the interaction with VR environments and GIS-based maps.

2.1 Interaction in immersive VR environments

The design of the interaction of an immersive VR environment poses specific challenges since it influences the task performance and also impacts the degree of immersion and presence the user will experience [6] which are two key benefits of using VR technology. Bowman [6], identifies three universal tasks in virtual environments: viewpoint motion control, selection, and manipulation. The first one refers to the actions the user carry out to change her position and orientation in the environment. The other two comprise the actions that modify the location and attributes of the virtual objects in it.

Most of the interaction solutions proposed to support these tasks can be classified into two categories: body-based and device-based techniques. The first ones use the own human body as input device. According to Slater and Usoh [32] the design of a body-centred interaction that matches the physical and virtual body movements enhances the feeling of being present in the virtual environment and this, in turn, affects engagement. On the contrary, devices-based techniques rely on an external object to capture the user input. Sometimes the device has been specifically designed for VR environments, such as the Oculus Touch, but in other cases it could be a standard game controller, such as the Xbox controller.

It is only recently that the possibilities of immersive technologies for supporting the data analysis task have started to be explored in different contexts. For example, Ferrand et al. [13] present a system for CAVE VR environments that aims to help analyzing astronomical data. The system provides a holistic view of the spectral radio data of a galaxy as a 3D model, instead of representing them using the traditional 2D projections. In the area of neurology, Usher et al. [34] proposes a VR system for interacting with 3D neurons representations using a Oculus Rift device. In this case the system seeks to facilitate the process of neuron tracing, a usually tedious and complex task carried out using 2D image stacks of the neurons. With a more general purpose, ImAxes [11] supports the creation of a variety of visualizations of multidimensional data by means of graphic plots whose data axes placed in an immersive 3D space. Other examples of immersive visualizations for representing and interacting with graphs and plots can be found in [18] and [16].

In the following sections, we briefly discuss the most popular interaction styles proposed for supporting each universal task in immersive virtual environments.

2.1.1 Viewpoint motion control techniques

Bowman et al. [7] distinguish five common metaphors for viewpoint motion (navigation henceforth) in immersive virtual enviroments: *physical movement*, which directly maps the user's movements into movements in the virtual world, *manual viewpoint manipulation*, that allow to navigate using hand motions or the direct manipulation of the camera, *Steering*, that require to continuously specify the direction of the motion, *Target-based travel*, in which the system automatically moves the user to a previously specified target location, and *route planning*, that requires to specify the path to follow.

Physical movement techniques are the most intuitive and natural, and they allow to maintain the sensation of presence in the virtual environment. However, most of the times they are difficulty to implement, due the limited physical space available for the user to move around. For this reason, most frequently the navigation in VR environments is implemented using some combination of steering and target-based techniques. In both cases, it is possible to design both body-based and device-based interaction solutions. For example, steering can be performed by pressing virtual buttons with the own user's hands or using a joystick, while the target location for the teleportation can be specified using the user's gaze or ray-casting from the device.

2.1.2 Selection and manipulation techniques

The overall user performance when manipulating entities or targets in VR environments is often determined by the way they are selected [3]. Two main metaphors can be identified when implementing interaction solutions for the selection tasks: virtual hands [27] and virtual pointing [23]. When using a virtual hands metaphor the user implicitly emulate the action of grabbing an entity using her own hands. In the case of the virtual pointing metaphor, it is necessary to perform some kind of gesture to indicate the position of the desired entity in the environment.

One of the main advantages of virtual pointing techniques over the hands metaphor is that they allow the user to select targets out of her reach without performing additional tasks like teleportation [3]. Among the different virtual pointing techniques proposed, ray-casting and gaze selection are considered the ones that support a more natural interaction in VR environments [23]. When using ray-casting, the selection is achieved by means of a laser beam projected from the user's hand or a device to the desired target. In the case of gaze selection, the user just looks at the desired target to select it.

Some researchers have investigated which of the possible implementations of these techniques is most effective. For example, Quian et al. [28] presents an empirical study that compares the selection performance when using three different techniques (eye, head and eye & head). The results suggest that the selection based only in head movements offers the best performance. Further research has compared Head Orientation Selection (HOS) and Laser Pointer Selection (LPS) techniques. The results of the study presented in [33] suggest that HOS provides an overall better performance. However, LPS seems to result more intuitive for the users, as they learn to use it faster.

2.2 GIS-based maps

As explained above, as GIS-based maps are frequently used in decision-making processes it is of paramount importance to implement an effective interaction solution that allows to rapidly operate the system. Although the range of operations supported by these systems vary depending on their specific purpose, they all require to provide two essential functionalities: map navigation and selection of points of interest.

2.2.1 Non-immersive environments

Most HCI works in the area of 2D maps interfaces have focused on identifying the most suitable interaction technique for performing these operations when using different types of displays devices [6], as tabletops, large displays and mobile screens. For example, Beheshti et al. [5] present a study that compares two input methods (i.e. mouse vs. touch input) for navigating maps in tabletops and desktop computers. The results obtained suggest that there are not significant differences in terms of performance. In case of large displays, hand gestures are considered the most intuitive interaction mode [1], while the usage of additional small displays called peepholes (e.g. a mobile screen) to partially show a much larger information space seems to improve the learning speed, the navigation speed, and reduces the task workload [29]. In case of mobile devices, Pahud et al. [26] have compared the performance of two navigation techniques: tracking the movement of the device in space (*Chameleon Lens*) and direct-touch gestures (*Pinch-flick-Drag*). The results of their experiment showed that *Chameleon Lens* is significantly slower for navigation tasks than *Pinch-flick-Drag*.

2.2.2 Immersive environments

In the case of VR systems, Yang et al. [36] evaluated the outcomes and limitations of four different ways of representing maps in an immersive virtual space: as a 3D exocentric globe (a 3D representation of the earth globe where the user visualizes it from the outside), as a flat map (the world is rendered to a plane in VR), as a curved map (the map is projected onto a section of a sphere which curves around the user), and an egocentric 3D globe (The viewpoint is inside the globe). The results suggests that the exocentric globe is the best choice when using the map for estimating distances and directions, while the egocentric representation is the least effective solution. In another work [35], the same authors explored different solutions for representing origin-destination flow maps that connect geographical locations. The results of this study indicate that 3D globe representations work better than flat representations in terms of accuracy, speed, and user preferences. Hurter et al. [15] also study the problem of representing flow maps. In this case they proposed a visualization based on a flat map named FiberClay to facilitate the analysis of large data-sets of multidimensional trajectories. In the case of the system proposed in [20], the focus is on the representation of geographic information and its application in educational contexts. Despite the valuable contributions of these works, their main concern is the representation of the information rather than exploring interaction techniques for exploring with it.

Among the works focused on map-based interaction, [17] proposes a interaction design for navigating maps using voice commands and point of interest density zooming for region search. Although this interaction style does not require a device to perform any gesture, its effectiveness in practice could be reduced due the limitations of speech and command recognition.

Finally, Giannopoulos et al. [14] present a preliminary research in which they present the outcomes of two interaction styles: one hybrid technique that combines the use of the head orientation and the buttons provided in the VR headset, and another based on head movements only. The result of this study suggests that the second technique is more effective.

Table 1 summarizes the main focus and findings of the different studies presented in this section. As shown in the table, most of the solutions proposed used as input device an external device or some part of the body (mostly the hands). In the case of the VR maps interfaces, the most frequently tasks evaluated are: pan, zoom, navigate, and selection. Not all the works analyzed included a formal evaluation of the system or interaction technique proposed. Despite the valuable contributions of the ones that included evaluations, their results do not provide clear guidelines on how to choose the interaction technique that best suits a VR system. Therefore, there is still a lack of studies that tackle the design of the interaction of map interfaces for immersive VR environments. The study presented in the next sections will try to fill this gap and contribute to better understand which interaction techniques are more effective for operating this type of systems.

3 Analyzing selection techniques for VR immersive maps

Taking into account that most of the interaction tasks presented in the literature review fall in the use of an external device (such as a gamepad), or the human body (such as the hands or the voice), our study present an empirical comparison of these interaction styles that we are going to group as Body-based when the interaction is performed with the support of some part of the human body, and Device-based when the interaction is performed with the support of an external device. The research questions that we try to answer by this research are:

1. Which is the most efficient interaction style for map interfaces in VR environments?
2. Which interaction style the users consider is the most usable for map interfaces in VR environments?

A classical approach in Human Computer Interaction for determining the efficiency of an interaction style is to measure the completion time for the task and the error rate [19, p. 26]. With regards of the interface usability evaluation, the SUS questonnarie [8] is frequently used as it allows to capture the the perception of usability from the users. Taking as a starting point the findings made in different works presented in the previous section, we state the following hypothesis:

H1: In VR environments, device-based interaction offers the lowest time selection for map interfaces.
H2: In VR environments, body-based Interaction offers the lowest error rate for selection in map interfaces.
H3: In VR environments, users consider that device-based interaction is the most usable mechanism for map interfaces.

To validate these hypothesis in VR environments, we designed an experiment in which participants interact with a GIS-based map interface implemented in a VR environment. In the following section we describe the design of the VR map interface and the different types of interaction styles it implements.

Table 1 Summary of studies for interactions techniques

Ref	Context	2D/3D	Type of display	Tasks supported	Interaction technique	Type of study	Evaluation results
[1]	Map Interface	3D	Cinema Display	pan, zoom, rotate	Hand gestures	Interaction Proposal	No evaluation study.
[5]	Map Interface	2D	Desktop screen, Tabletop	Map navigation	Mouse, Multi-touch Gestures	Comparative Study	No difference between the interface type.
[29]	Map Interface	2D	Large screen	Map navigation	Peephole navigation, Controller	Comparative Study	Larger peepholes improve learning, navigation, and reduce task load.
[26]	Map Interface	2D	Mobile screen	pan, zoom	Chameleon Lens, Pinch-flick-drag, Hand Gestures	Comparative Study	Chameleon Lens is significantly slower than Pinch-Flick-Drag.
[17]	Map Interface	2D	Smart Glass	Zoom	Point of interest Density, Voice	Interaction Proposal	No evaluation study.
[14]	Map Interface	2D	HMD	pan, selection, zooming, combination	Head movement, button pressing in the HMD	Evaluation Study	Head movement for input is natural and effective, avoid external tactile controls.
[15]	Multidimensional data visualization system	3D	Immersive displays	Navigation, manipulation	Controller	Interaction Proposal	The system allows the user to efficiently select trajectories.
[20]	Geography learning	3D	HMD	Navigation, manipulation	Gestures	Technology Exploration	No evaluation study
[35]	Flow Maps	2D, 3D	HMD	Visualize flows	None	Comparative Study	Careful use of the third spatial dimension can resolve visual clutter.
[28]	General Purpose	3D	HMD	Selection	Head Orientation, Gaze	Comparative Study	Head Only selection offer better performance.
[33]	General Purpose	3D	HMD	Selection	Head orientation, Ray casting	Comparative Study	Head Orientation Selection allow users to have better overall performance.

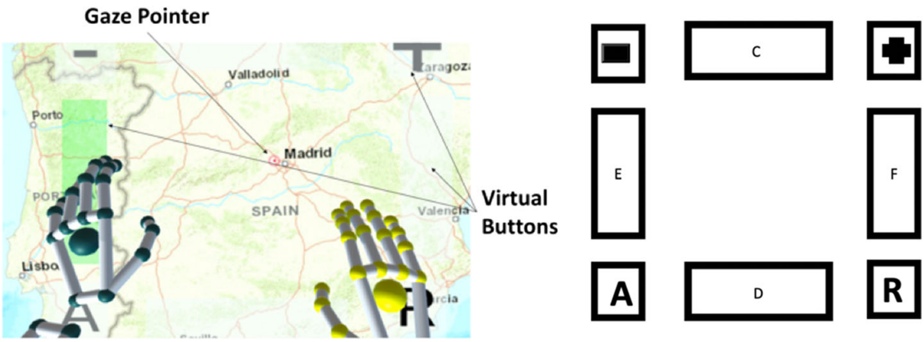

Fig. 1 (Left) Map Interface in Virtual Reality Environments using body-based interaction. (Right)Virtual buttons schematics: A. add, R. Remove, +. Zoom in, -.Zoom out, C.Move up, D. Move down, E. Move left, F. Move right

4 The VR map interface

To compare the outcomes of the two interaction techniques we implemented an immersive VR application for controlling maps. The application was developed in Unity, and it is intended to be used with the Oculus Rift. When the user wears the HMD she is moved into a virtual space, looking at a wall displaying a map (see Figs. 1 and 2). In order to present as much information as possible, the wall occupies the whole user's field of view. We followed this approach to try to reproduce the way information is displayed in the large screen displays frequently used in emergency control centers, for example. The current implementation of the system supports the following functions:

– Pan the map left, right, up and down.
– Zoom in/Zoom out.
– Place/Remove a marker in the map.

Fig. 2 (Left) Map Interface in Virtual Reality Environments using device-based interaction. (Right) Oculus touch button distribution: A. Thumbstick, B. Index trigger, C. Hand trigger

The design of the body-based and device-based interactions for these functions was informed by the outcomes of the works reviewed in Section 2, our previous studies in the area of immersive virtual environments, and a series of tests with users. For example, we explored the possibility of mapping directly the pan and zoom operations to user's gestures, as "grasping" the map with the hand and making a drag and drop movement. However, the users reported to find difficult to perform this action correctly. We also tested the possibility of controlling the map by directly extending the arm towards the direction the user aims to pan. This approach soon revealed inadequate as it led to many mistakes. Also, the final layout of the virtual buttons was deviced after testing several configurations and positions in the virtual space. With regards of the device, we chose the Oculus Touch over the xBox controller as the results of a previous study [37] showed that users who do not play videogames could find difficult to locate and press the buttons of the later while wearing a HMD that impedes the vision of the device.

Taking into account the different works presented in Section 2 where interaction styles mostly fall into the use of a device or gestures performed by the human body, and the preliminary studies performed, we implemented two different ways of controlling the map: one using a body-based interaction style, and device-based interaction style.

4.1 Body-based interaction

The body-based interaction makes use of a Head Orientation Selection technique for selecting positions in the map, and some virtual buttons displayed over the map that the user press with her own hands. The user points with her head to the position of the map she wants to zoom in/out or in which she wants to place a marker, and press the virtual button corresponding to the function with her own hands (Fig. 1-right indicates the function of each virtual button). Furthermore, the user can use both hands to interact with the virtual buttons. This solution allows the user to control the map using the body. To track the user's hands and display them in the virtual world we used a Leap Motion Sensor. Figure 1-right shows an schematics of the virtual buttons presented to the user.

Figure 1-left shows a screenshot of the VR map interface when using this interaction style. As shown in the picture, in order not to obstruct the vision of the map, the virtual buttons are semi-transparent, and they only change their color to green when they are pressed. The head pointer is displayed as a red circle.

4.2 Device-based interaction

The second interaction style uses the Oculus Touch controller. This device not only allows to track the user's hands and display them in the virtual world, but it also provides several buttons and a joystick for each hand. To select positions in the map, we implemented a LPS technique, simulating a laser pointer that the user activated by pressing the *Thumbstick* button (Fig. 2.A-right). To scroll the map, the user just needs to move the joystick in the desired direction. Finally, the button triggers *Hand trigger* (Fig. 2.C-right) and *Index trigger* (Fig. 2.B-right) allow to zoom in/out the map, or add/remove markers when the joystick is pressed. Furthermore, the user can interact with the interface using the controls of each hand (only one of them at the same time). The entire button distribution of the Oculus Touch controller can be seen on [25].

Figure 2-left depicts a screenshot of the VR map interface when using this interaction style. As shown in the picture, the laser pointer is displayed as a green ray.

5 Experiment description

In the following section we describe the characteristics of the experiment: participants, apparatus, environment, methodology and data collection mechanisms used in the experiment.

5.1 Participants

Thirty-two participants (aged M = 22,78, SD = 5,07, 20 males) performed the experiment. The background of the participants was on computer science (22), five on HCI and interaction design, three PhD students, and fourteen undergraduate students. The rest of participants were students in Telecommunications, Biomedical and Civil Engineering. All participants had have previous contact with virtual map interfaces as google maps (M = 4 times per week). Most of the participants had used VR HMDs before, but none of the participants used them regularly. Fifteen participants do not use glasses, and seventeen participants use glasses. Participants received no compensation, and informed consent was obtained from all individual participants.

5.2 Apparatus

We used the following equipment for the experiment: Oculus Rift HMD for visualizing the virtual environment, a Leap Motion Sensor attached to the HMD for the body-based interaction style, an Oculus Touch control for the device-based interaction strategy, and a desktop computer for the processing and execution of the map interface. A detailed description of the apparatus used in the experiment can be seen on [31].

5.3 Experimental environment

We ran the experiment on the Interactive System Lab at The University Carlos III of Madrid in Spain. The participants carried out the experiment sat on a chair, as shown in the Fig. 3.

5.4 Experiment methodology

The study design was within-subjects as this type of studies allow to observe the behavior of the same user with both interaction styles, and it requires a fewer number of participants.

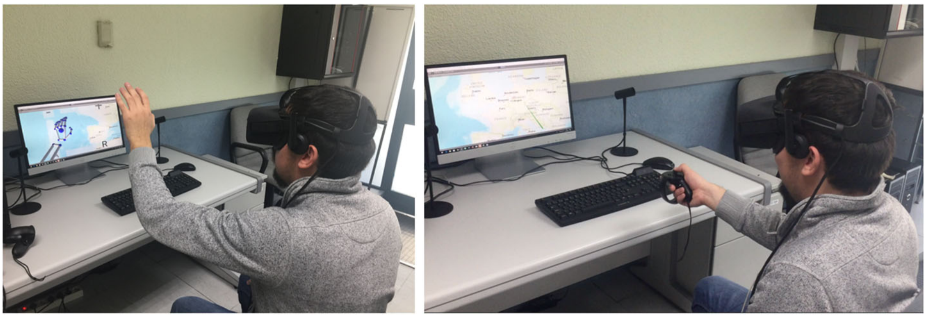

Fig. 3 Experimental environment: body-based solution (left side), device-based solution(right side)

The first interaction style was randomly chosen in order to avoid possible bias due to the learning effect. The independent variable is the Interaction Style which can be body-based interaction (Head Pointing Selection + Hand Gestures) or device-based interaction (Laser Pointing Selection + Oculus Touch Control). We used the same dependent variables as in our previous study [31] and, therefore, for each condition we measure the time spent to carry out the activities; number of errors; and the perceived usability.

5.5 Procedure

Each participant of the experiment took around 20 minutes to execute the activities of the experiment. First, participants receive basic information about the experiment and the activities that they have to do. Then they completed a pre-test that collects demographic data. Then, the first interaction style was randomly assigned in order to avoid possible bias due to the learning effect (17 participants started with the body-based interaction style), and the participant sat approximately 60 cm from the sensors of the Oculus HMD. Then, the subject use the VR environment in order to get familiar with the GIS interface and the interaction style. In the training session, a researcher explained how the map interface works, the button distribution, and the functionalities the system supported. The researcher explained the participant that the system could be operated using either her left or right hand. Then, the researcher invited the participant to freely interact with the interface until she felt confident using it. Once the training was completed, the system displayed the name of a city and the participant was asked to place a marker at its location as quickly and accurately as possible. The names of the cities appeared near its geographic position in the same the way map interfaces show the names of cities when user navigates. This task required to use the designated interaction style input method to pan and zoom around the map, and to mark the city using the corresponding technique. If the user made a mistake and unintentionally placed a marker in the wrong place she could delete it. Once the user indicated that the marker was correctly placed, the researcher pressed a button and the application displayed the name of a new city. This process was repeated 12 times, with each city representing a trial. The cities were presented in the same order to all the participants: 1) Paris, 2) London, 3) Lima, 4) New York, 5) Moscow, 6) Madrid, 7) Berlin, 8) Brussels, 9) Rome, 10) Buenos Aires, 11) Vancouver, 12) Quito. Finally, the interface automatically collected and saved performance data, and participants were asked to fill usability and user experience questionnaires as described below. The same activities were then repeated using the other interaction style.

5.6 Data collection and analysis methods

The application collected automatically the time taken from the moment the name of each city was displayed until the participant indicated that she placed the marker. Also, the system calculated the number of errors per city as the number of markers placed minus one (the last and valid one), and stored the coordinates of the marker. Finally, the overall time of whole task was measured from the moment the name of the first city was displayed till the last marker was putted on the map (considered as the most accurate one).

We used the SUS questionnaire [8] to collect the value of perceived usability from the user. This questionnaire was filled after finishing the 12 trials. Furthermore, participants filled an extra questionnaire at the end of the whole experiment in order to provide insights about their experience when using each interaction style. More specifically, we asked them to rate in a scale from 0 (very low) to 5 (very high) a set of factors that might affect the experience: general effort, precision of the selection and comfort during the experience.

Also, a open question was included for collecting additional information on the participant experience, suggestions and improvements of the GIS VR map interface.

To analyze the data, we performed a Wilcoxon signed-rank test in SPSS. A non-parametric test used to find statistic differences between Body-based and Device-based interaction style.

6 Results and analysis

6.1 Selection time

Figure 4 summarizes the means of the selection times for each of the 12 trials per interaction style. For analyzing all dependent variables, a Wilcoxon signed-rank test was used with a significance level of $\alpha = 0.05$. A Shapiro-Wilk test indicates the non-normal distribution of the data ($p < 0.001$).

The Wilcoxon Signed-Ranks Test indicated that the selection time for Body-based interaction style (Mdn = 22.89) was statistically significantly higher than the selection time for Device-based interaction style (Mdn = 17.53) $T = 58$, $p < 0.001 r = -1.11$.

As shown in Fig. 4, the device-based interaction has the lowest time selection mean in all trials. These results confirm our initial hypothesis, suggesting that users take less time to navigate and put markers in VR map interfaces when using a control device.

6.2 Error rate

The means of the number of errors per trial are summarized in Fig. 5. The Wilcoxon Signed-Ranks Test indicated that the selection time for Body-based interaction style (Mdn = 0.4837)

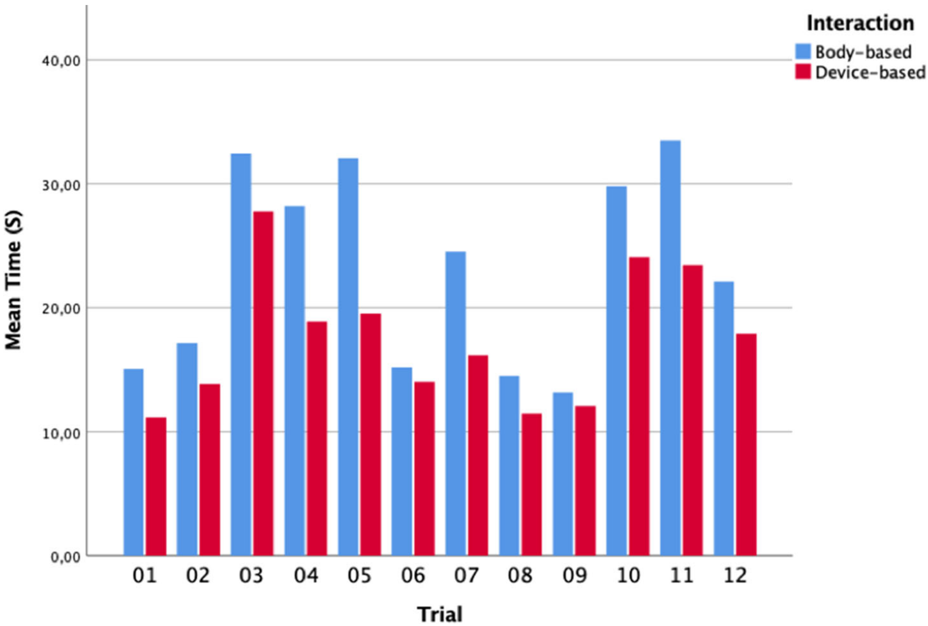

Fig. 4 Time selection means per trial

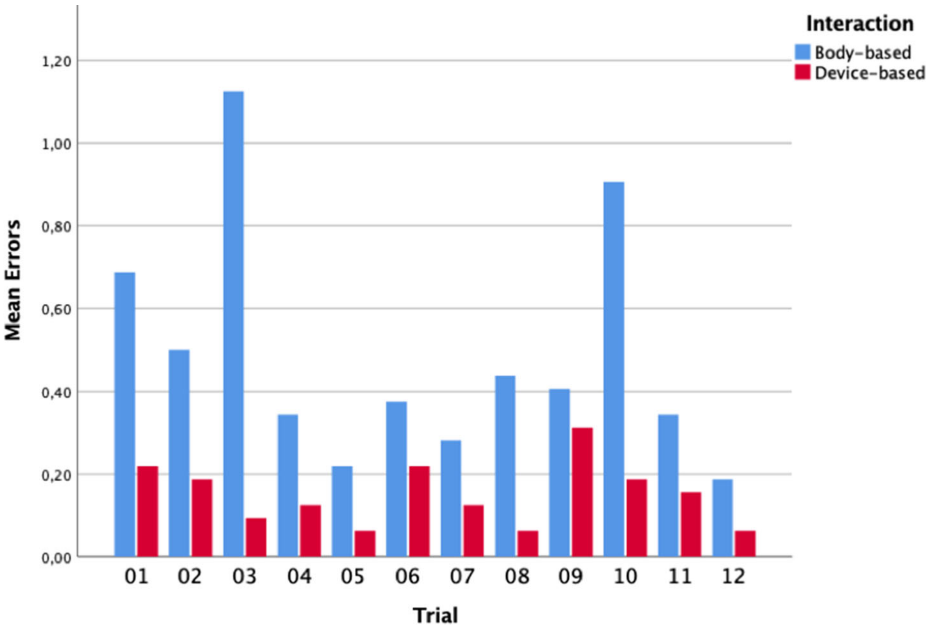

Fig. 5 Error means per trial

was statistically significantly higher than the selection time for Device-based interaction style (Mdn = 0.15) $T = 40.5$, $p < 0.001 r = -1.11$.

These results reject our initial hypothesis, suggesting that users make less mistakes when using body-based interaction.

6.3 Learning effect

We perform a correlation analysis in order to identify if there is any relation between the trial and the time for completing the task, and any relation between the trial and the numbers of errors. A Spearman's correlation analysis shows no significant relationship between the trial and the time for completing the task, and no significant relationship between the trial and the number of errors. Table 2 summarizes the results for time completion task, and Table 3 summarizes the results for number of errors. These results suggest that there was no learning effect during the experiment due the order the cities was displayed.

Table 2 Summary of correlations between trial, time, and interaction style

	Trial	Interaction style	Time
Trial	1	0.000	0.180
Interaction Style	1.000	1	-0.385
Time	0.401	0.063	1

Table 3 Summary of correlations between trial, error, and interaction style

	Trial	Interaction style	Errors
Trial	1	0.000	-0.184
Interaction style	1.000	1	-0.785
Number of errors	0.390	0.001	1

6.4 Usability reported by users

Interaction usability differences are summarized in Fig. 6. The results of the paired samples t-test show that there was a statistically significant difference between body-based (M = 73.75, SD = 13.10) and device-based (M = 83.04, SD = 12.30) interaction conditions; $t(31) = -2.691$, $p = 0.011$.

As shown on Fig. 6, the participants gave a higher rating to the usability of the device-based interaction style. These results confirm our initial hypothesis.

6.5 User experience

Figure 7 summarizes the participants' responses to the experience questionnaire. As expected, there seems to be a general agreement in considering that the experience was more physically demanding when using body-based interaction. Also, the rating of comfort and effort favored the device-based style. However, although the participants ended the experiment less tired when using the Oculus Touch, the difference between the body-based and device-based interaction rating was not very high.

With regards to the selection accuracy, the participants rate higher the one obtained by the laser pointer. Again, there is not a great difference with the one obtained when using the head.

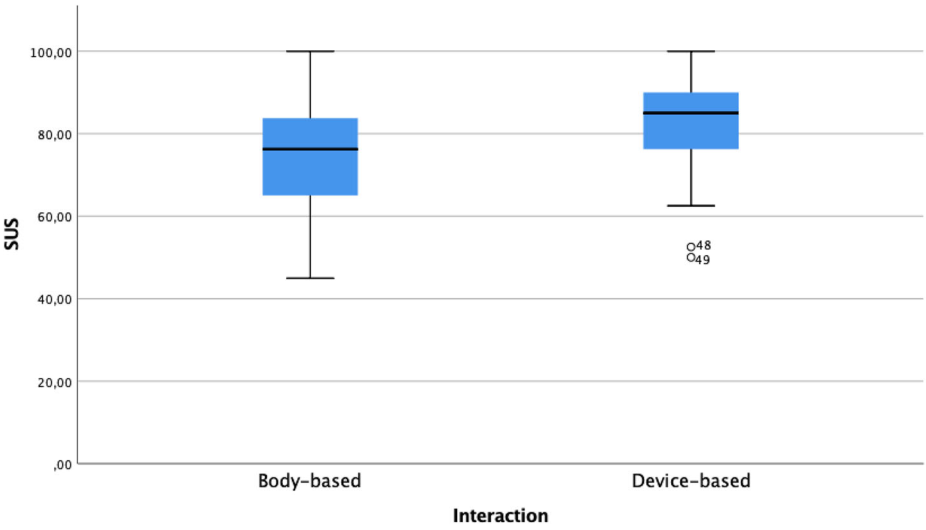

Fig. 6 Usability values reported by users

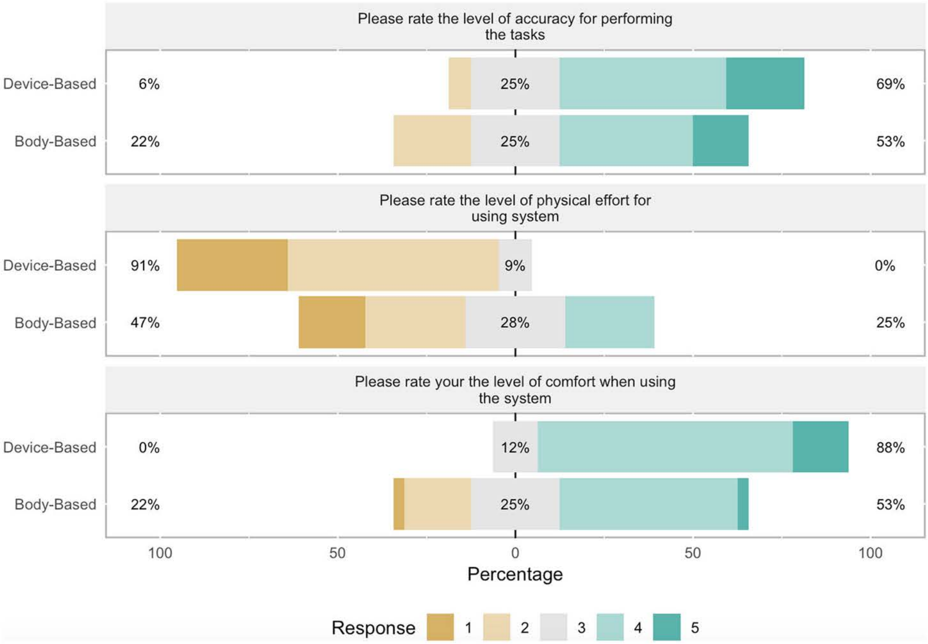

Fig. 7 Participants' rates for comfort, effort and selection accuracy

6.6 Participants comments

Table 4 presents a summary of the participants' comments and responses to the open questions. To help us identifying patterns the comments were grouped and categorized into three categories: positive comments, negative comments, and suggestions. The number at the beginning of each phrase represents the number of participants who made that type of comment.

As showed in Table 4, in general, the comments gathered from the participants are consistent with their responses to the usability test. According to their comments, the participants seem to consider the device-based interaction style as quite comfortable to use, as this is the most frequently observation (13) reported about this experience. The participants seemed to value the haptic feedback provided by the device when performing the task. As one of them stated: "... it feels comfortable to use the controllers as you have something to hold (there is a feedback between the command and the action)...". On the negative side, some participants (9) considered the button distribution confusing, and 3 suggested to improve it. It is necessary to note that the buttons functions were assigned taking as a example some commercial applications. Although there is no general agreement about it, more participants considered this technique inaccurate (10) than accurate (5). This disagreement could be explained by the different level of the hand accuracy for pointing the places that the participants exhibited when placing the markers. Finally, 2 participants reported that the interaction "felt unnatural".

With regards to the body-based interaction style, the most frequently comment reported is negative: 18 participants considered this technique as "confusing to use". A possible explanation might lie in the button touch sensitivity, which 3 participants reported to feel too

Table 4 Comments given by the participant about each interaction style

Interaction style	Positive	Negative	Suggestion
Body-based	(3)Felt the interaction more natural. (2)Easy to learn after some time using it. (4)Better precision using the head.	(3) Found the buttons too sensitive when pressing. (18)Confusing to use.	(1)Move the map by using the head.
Device-based	(13)Comfortable and easy to use. (5)Accurate interaction.	(9)Get confused with the purpose of each device's button. (10)Inaccurate interaction. (2)Unnatural interaction.	(3)Improve button distribution.

high. Also, the observation of the experience revealed that sometimes participants pressed buttons unintentionally. On the positive side, the participants seems to consider this technique natural (2) and easy to learn (2). Also, 4 participants highlighted in their comments that this interaction was more precise than the other.

Finally, during the experiments we found particularly interesting the fact that participants showed different behaviors when searching and selecting locations in the map. Some of them preferred to navigate and zoom the map until the location to select was clearly visible in the map. On the contrary, some others position themselves in the map so they were able to select several locations just by turning their head or changing the orientation of the ray-casting. The time these latter participants required to select a location was considerable smaller than the former ones.

7 Discussion

The results of the experiment suggest that the device-based interaction performs better for controlling immersive VR maps than body-based interaction, and that the users perceived the former technique as more usable. In any case, when analyzing these results, it is necessary to consider that most participants had none or very limited previous experience with VR systems. This means that most of them never used a body-based interaction style before, whereas due to their age (aged M = 22,78, SD = 5,07) it can be expected that all had used a game control. Therefore, even though in principle the body- based interaction could felt "more natural", as it mimics better how people interact with objects in the real life [24], the use of joystick and buttons to control an application might be more familiar for them. In any case, it is also necessary to take into account the physical effort required to use the system. According to the results collected, most participants rated the effort required to control the system with the body-based technique as "medium". As most of them completed the tasks required for each interaction style in about 10 minutes, it can be expected that when using the system for longer periods the results might be different for both interaction styles, specially once the "wow effect" dissipates.

In any case, the use of a device-based solution is not exempt of problems. This technique require the user to memorize and remember the function of each button and trigger in the device. As the number of functions provided by the VR map application increases, implementing an interaction solution based on a single interaction device would become more difficult. To overcome this problem the designers of the application could consider to implement a multi-modal interaction style that combine the two techniques or that make use of command voice control, for example.

8 Limitations and future work

With regards to the limitations of the study it is necessary to note that there exist many other possible ways of controlling a map using body and device-based interaction styles. However, and as explained in Section 4, the two solutions implemented for the experiment were chosen after testing different alternatives in preliminary studies. In the same way, we tried different layouts for the virtual buttons and assignments of functions to the controller's triggers and buttons before selecting the ones used in the experiment. Also, we have to take into account that we grouped interaction styles by the use or not of a external device to interact with the interface. In our future work, we will test how hybrid solutions such as the combination of head pointing selection and a controller works when interacting in immersive environments.

It is also possible that the results of the study might be influenced by the participants age, as most of them were between 20 and 25 years. It stands to reason that young people are used to use gamepads for playing games, and therefore they are familiarized with the use of interaction devices for controlling applications. Also, and in order the users' previous knowledge on geography not to interfere in the experiment, all the cities were well-known. The behavior of the user when exploring the map searching for an unknown location might be different, and the selection time could be then affected.

9 Conclusions

Immersive VR technology offer interesting possibilities for analysing geo-spatial information. However, in order to fully exploit its potential it is necessary to better understand the human factors involved in the design of these types of environments. In this work we presented a comparative study between two body-based and device-based interaction solutions for interacting with this type of systems. Despite the fact that body-based interaction offer a more natural way to interact with VR environments, our study provides insights that suggest that device-based interaction style could be a more efficient way to interact in VR maps interfaces in terms of time selection, error rate, and usability.

In our future work we want to investigate the benefits that immersive VR might report as a support for map visualization when compared with traditional methods based on tabletops or large screens.

Acknowledgments This work is supported by the project PACE funded by the Spanish Ministry of Economy, Industry and Competitiveness (TIN2016-77690-R).

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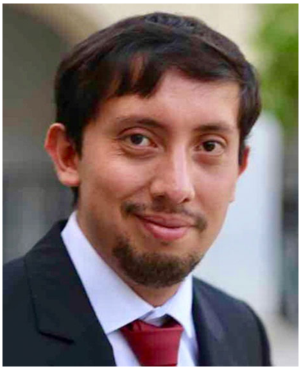
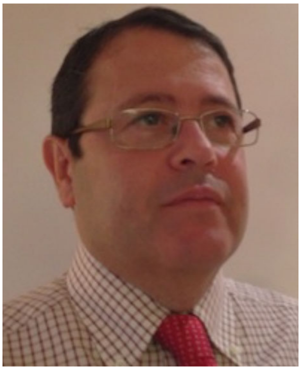


Andrés Santos-Torres holds a Degree in Electronic Engineering and Networks from Escuela Politécnica Nacional de Ecuador (2014). In 2016 he receives a full scholarship from Fundación Carolina - Spain to do his M.Sc. in Computer Science from Universidad Carlos III de Madrid (2017). He is currently doing his P.hD. at the same university. He is a member of the LAB DEI research group (dei.inf.uc3m.es) focused on the research of interaction paradigms for virtual and augmented reality. He has been teaching assistant at Escuela Politécnica Nacional de Ecuador (2015 - 2016).

Telmo Zarraonandia holds a Degree in Computer Science from the Universidad de Deusto and a Ph.D. in Computer Science from Universidad Carlos III de Madrid where he is currently associate professor. He is a member of the LAB DEI research group (dei.inf.uc3m.es) focused on the design of interactive systems applied to different domains such as education, emergency and crisis management, or cultural heritage.His research interests include technologies to support education and learning, videogame design, mixed reality environments and interactive systems. He has been visiting researcher at the Universidad Federal do Rio de Janeiro (UFRL) and at the Universitá degli Studi di Salerno (Italy). He has published several scientific papers in international journals and conferences related to the field of computer supported education and interactive systems.

Paloma Díaz is Full Professor in the Computer Science Department of University Carlos III de Madrid. She is the head of the LAB DEI research group (dei.inf.uc3m.es) focused on the design of interactive systems applied to different domains such as emergency and crisis management, elearning, or cultural heritage. Her main research interests include interactive systems engineering, collaborative systems, visualization and ubiquitous computing. Concerning the topics of this chapter, she has led projects on interactive and educational systems modeling and on the definition of conceptual frameworks for the codesign and production of serious games supporting children informal learning. She has been visiting scholar in the Information Science and Technology College of PSU, the MAGIC LAB of the University of British Columbia and the ViSUS Institute of Stuttgart University.

Teresa Onorati is a visiting professor at the Computer Science Department of Universidad Carlos III de Madrid, where in 2013 she received her PhD in Computer Science, modelling the semantics of several knowledge domains for improving the accessibility of critical information. She also holds a B. Sc. and a M. Sc. in Computer Science from La Sapienza Universitá di Roma. As a member of the DEI Interactive Systems Research Group in UC3M, she is involved in several research projects about the role of technology for improving citizen collaboration and participation in critical situations. She has been a visiting researcher at the Researcher Center INRIA-Saclay (Paris, France) working on large display interaction, and the GEO-Vista Research Center, PennState University (Pennsylvania, USA) working on visual analytics for geographic information. Her research interests focus on semantic modelling, visual analytics and information visualization for supporting a better understanding of how information and people sentiments propagate within a complex data ecosystem.



Ignacio Aedo holds a degree and a PhD in Computer Science from Universidad Politécnica de Madrid. He's currently full professor at the Universidad Carlos III de Madrid (Escuela Politécnica Superior). His research interests include hypermedia, interactive systems in education, web systems, electronic books, development methodologies and information systems for emergency situations. In 1990, he started his research activity in the field of interactive systems on which he is still involved. He has been visiting researcher at CSCL of IST Pennsylvania State University (2007-2008) and MAGIC of University of British Columbia (2011). Chair of a groupVision Grant for Technologies for the Collaboration; Co-Chair of IEEE ICALT 2008, 2009, 2010 and 2012; Subdirector of Culture and Technology Institute and Deputy Vice-Chancellor for Faculty and Departments (UC3M).