

CONTROLLING 3D GEOVISUALIZATIONS ON TOUCH SCREEN – THE ROLE OF USERS AGE AND GESTURES INTUITIVENESS

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Abstract

The use of touch displays and 3D visualization are both increasing. Devices with touch displays are used daily, especially by the younger generation, who are also known as digital natives. This paper examines a comparison between digital natives and adults (so-called digital immigrants). We created a pilot user experiment (within-subject design, two tasks, Acer LCD touch monitor and digital terrain models textured with satellite images as stimuli) testing the ability of participants to solve simple spatial tasks by manipulating a 3D environment on a touch screen. The tasks required a hidden object to be found in the terrain. Our own testing tool, called 3DtouchR, was used for this purpose. Response time, gestures used, and virtual movements were recorded and analysed. Results revealed that digital natives were quicker with interaction (shorter response times and average speed of virtual movements). The success of solving each task was evaluated by determining the distance between the searched object and the virtual camera's final position. An analysis of gestures used revealed a higher frequency of pan gesture usage in all test participants.

Keywords: 3D geovisualization, 3DtouchR, 3D Touch Interaction Recorder, human computer interaction, user issues, touch screen.

INTRODUCTION

Interactive 3D visualizations of geospatial data are employed today in many fields to deal with many issues. These visualizations are displayed on a wide range of devices, including those controlled via touch screens. Both adults and children are confronted with 3D visualizations and touch screen devices. Working with them, however, is more natural for the younger generation, as these “digital natives” (Prensky 2001) have grown up surrounded by digital technologies and are accustomed to receiving information quickly. By contrast, working with touch screens or digital technologies is generally not so obvious for adults, who are referred to as “digital immigrants” (Prensky 2001).

Research focusing directly on digital natives (children or adolescents) working with geospatial data is not well established. As examples, Kubiček et al. (2017), Kramářeková et al. (2016), Schnürer, Sieber and Çöltekin (2015), Bandrova and Konečný (2014), Svatoňová and Rybanský (2014), or Jokisch, Bartoschek and Schwering (2011) can be mentioned. We therefore decided to compare how digital natives and digital immigrants work with interactive 3D geovisualizations on touch screens. The aim was to compare the results and strategies used in this experiment to describe the differences and also suggest possible optimizations.

RELATED RESEARCH

The usability of 3D geovisualization is an issue that has been analysed from different perspectives by several authors (Kubiček et al., 2017; Juřík and Šašinka, 2016; McKenzie and Klippel, 2016; Herman and Stachoň, 2016; Schnürer, Sieber and Çöltekin, 2015; Wilkening and Fabrikant, 2013; Abend et al., 2012; Bleisch, Dykes and Nebiker, 2008), but relatively little is known about the effects of using interactive techniques, such as touch screen control. User interaction with 3D visualization of geospatial data via touch screens was therefore examined.

Bleisch, Dykes, and Nebiker (2008) assessed the possibility of 3D geovisualization when comparing the differences between the reading heights of 2D bar charts and reading those bar charts placed in a 3D environment. Speed and correctness of answers were measured, but information about the movement data were not recorded and evaluated, even

though interaction in the 3D environment was enabled. Wilkening and Fabrikant (2013) studied interaction through observation and manual recording of the movement types (zoom, pan, tilt, and rotation). Špriňarová et al. (2015) described a mainly qualitative (and to some extent subjective) approach to research in which participants were observed using similar movement strategies and sequences in a 3D virtual environment, including a terrain model. In all these cases, an approach called screen logging would have made it possible to determine whether users employed the interactive capabilities of 3D environments or based their decisions on visualization only. Abend et al. (2012) have also contributed to analysing interactive navigation by processing videos captured while a user worked with 3D geospatial data. Subsequent analysis of videos is, however, more demanding than evaluating screen logging data, which can be analysed more objectively and with full automation. McKenzie and Klippel (2016) dealt with the problem of wayfinding in a virtual environment and analysed, for example, movement speed recorded via screen logging. Likewise, Treves, Viterbo and Haklay (2015) tracked and analysed the movement of their participants using virtual trajectory.

Touch screens and user interaction through touch screens is the second area which can be studied. White (2009) considered touch screens as an interesting solution for pointing, as they unite the input and display to produce a more natural metaphor of real-world interaction. Marchal et al. (2013) focused on designing an intuitive system of multi-touch techniques for interaction with 3D geospatial data. They proposed a system of touch and multi-touch gestures called Move&Look. The participants in this study compared this system to other techniques. Nurminen and Oulasvirta (2008) and Jankowski, Hulin, and Hachet (2014) dealt with interaction via the touch screens of mobile devices. Daiber (2011) presented another specific type of touch interaction. His study looks at interaction with stereoscopically depicted 3D geospatial data. Jokisch, Bartoschek, and Schwering (2011) studied the work done with touch screens according to the age of the experiment's participants. They tried to identify the most intuitive gestures when working with a touch screen variant of the Google Earth application. The most intuitive gesture was found to be rotating the 3D model by moving one finger on the screen. None of the studies mentioned above used the advantages of the screen logging method. The most used methods were observation and other subjective methods (e.g., Jokisch, Bartoschek and Schwering, 2011 – direct observation and think aloud protocols).

Generally, user-friendliness is an important feature of geovisualizations, so it needs to be verified with user testing. Sometimes usability and other user aspects are also required by legislation (Řezník, 2013). Most of the usability studies in cartography have used static 3D visualizations (perspective views) as stimuli. If interactivity was possible, it was not monitored or analysed in detail. Wilkening and Fabrikant (2013), Treves, Viterbo and Haklay (2015), and McKenzie and Klippel (2016) are exceptions, their approaches being the sources of our inspiration, especially utilization of the screen logging method. At the same time, we want to improve these approaches and adapt them to touch screens where screen logging has not been fully employed elsewhere.

EXPERIMENTAL TESTING

A simple within-subject design was chosen for the experiment. The test battery comprised two parts. The first part was a short questionnaire examining the age group and previous experiences with touch screen devices (smartphones, tablets). The second part contained two simple spatial tasks. Both tasks required to find an object hidden in the terrain. See online available video for a detailed understanding of the experimental testing (http://olli.wz.cz/webtest/3dtouchr/visualizations_iccgis2018).

Methods and technologies

An Acer FT240HQL LCD monitor was used as the input device for our experimental testing. This touch screen has a diagonal size of 23.6" (approx. 60cm) and the experiment was performed with a resolution of 1920 x 1080 pixels. This monitor was connected to a standard laptop computer (with Windows 10 operating system).

Our own tool, called 3DtouchR (3D Touch Interaction Recorder), was the software used for this experiment. 3DtouchR is based on open web technologies HTML (Hyper Text Markup Language), PHP (Hypertext Preprocessor), JavaScript (JS) and JS libraries X3DOM (for 3D interactive visualization) and Hammer.js (for gesture recognition). 3DtouchR is a special variant of a more general tool called 3DmoveR (3D Movement and Interaction Recorder). The design, development and functionality of 3DmoveR, including methods for visualization or statistical analysis of user interaction and virtual movement, are described by Herman and Stachoň (2016) and Herman et al. (2018). In addition, 3DtouchR records interaction via a touch screen such as the gestures used, and in the case of pan gestures (movement of one finger across the screen), also its direction of movement. The design process (e.g., evaluation of JS libraries for gesture recognition and selection of the most appropriate) and development of 3DtouchR has been published (Herman et al., 2016).

Stimuli

Digital terrain models formed the stimulus material. Terrain models from two neighbouring areas in North America acquired by SRTM (Shuttle Radar Topography Mission) were used. These data were processed in ArcGIS 10.2, and concretely in the ArcScene module. Base heights were double the real altitude and the DTM was layered with satellite images obtained via freely available WMS (Web Mapping Service). Finally, the digital terrain models were exported to VRML (Virtual Reality Modelling Language) files, converted into X3D files and loaded to 3DtouchR. Objects to be searched (task 1: windmill, task 2: water tower) were placed manually in the terrains (Fig. 1).

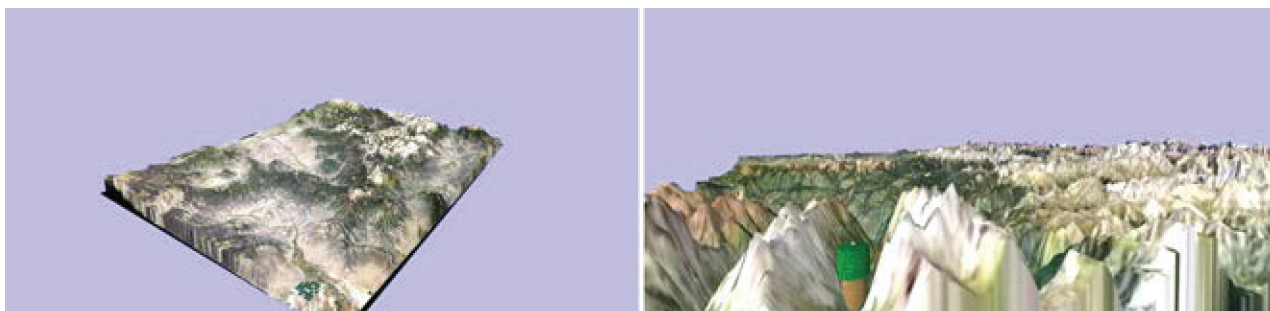


Fig. 1. Stimuli for task 1 (left – initial view) and task 2 (right – final view of participant N02).

The following gestures were differentiated: pan, pinch, tap and press. Pan (one-finger press, move, lift) rotated the 3D scene (orbiting) and is supported in a variety of technologies; see Herman et al. (2016). Pinch (two-finger press, move outwards or inwards, lift) zooms in or out. Tap (one-finger short press, lift) and press (one-finger press, wait, lift) were not required for movement in the 3D scene and were applied either inadvertently or when tapping on the button “Completed, continue”, which was placed below the 3D scene.

Participants

Participants in this experiment were attendants of the “European Researcher’s Night” at the Department of Geography, Masaryk University. Only 18 out of 48 participants correctly completed the tests. Each test’s progress was monitored by direct observation. If the test was handled by more than one person or a person attempted the test for a second time, these attempts were discarded. People aged 10 to 20 years were considered digital natives. Four males and five females participated as digital natives. Participants aged 30 to 60 years were considered digital immigrants (5 males and 4 females).

The experimental conditions were equivalent for all participants, including all environmental factors such as noise, lighting, etc. All participants agreed to the procedure and participated voluntarily and could withdraw from testing at any time. Their instructions were to complete the spatial tasks by finding the given object and moving as close as possible to it. They were informed that their performance would be monitored and that they could also quit the experiment at any time.

As mentioned above, users completed a brief questionnaire in the first part of the test (gender, age group and touch screen experience). For the question asking how often they worked with touchscreen devices, 5 digital natives answered “daily”, 2 answered “regularly”, 1 answered “occasionally” and 1 answered “rarely”; 4 digital immigrants answered “daily”, 2 answered “occasionally”, 2 answered “rarely” and 1 answered “never”. The questionnaire was completed on the touch screen so that participants were familiarized with the touch screen controls.

RESULTS

Data about touch interaction and the virtual movement were collected using 3DtouchR and then analysed and visualized. The task solving speed (response time), gestures used and measurements derived from the virtual movement trajectory were studied.

Tab. 1. Differences between digital immigrants and digital natives – mean values and standard deviations.

		Task 1				Task 2			
		Dig. immigrants		Dig. natives		Dig. immigrants		Dig. natives	
		mean	stdv	mean	stdv	mean	stdv	mean	stdv
Response time [s]		89.63	41.79	47.49	29.74	79.75	33.76	41.15	28.31
Length of virtual trajectory [km]		2975.96	2156.92	2829.33	1874.06	2762.25	1538.10	2856.87	2174.82
Average speed [km/s]		33.53	20.91	67.04	35.06	35.18	12.92	70.27	28.72
Total rotation [°]	Orthodrome centre angle	47836.53	24690.17	40759.02	27967.51	66671.79	26185.08	45938.85	42828.01
	Horizontal (yaw)	1406.49	653.02	1663.54	1519.87	4807.92	6848.30	2451.64	2208.36
	Vertical (pitch)	2144.86	963.14	2362.49	1784.29	3185.81	1725.19	2754.12	2262.47
Average height of virtual camera [m]		39334.17	23031.38	56118.79	28184.55	54699.63	9205.70	68961.29	27376.86
Delay at the beginning of solving a task [s]		6.20	5.65	2,51	1.40	3.29	1.66	1.59	0.16
Total duration of individual gestures [s]	Pan	56.28	33.90	33.04	22.14	61.65	29.09	31.83	22.43
	Pinch	21.62	19.80	7.02	7.80	12.88	15.89	6.27	6.65
Number of collisions with terrain		5.56	4.95	4.78	5.53	4.56	5.46	2.22	4.02
Distance to searched object at the end of solving a task [km]		46.46	37.42	48.39	28.12	59.36	39.32	76.83	49.02

The results showed that digital natives could solve both tasks more quickly (Tab. 1). However, the average lengths of virtual trajectories were similar for both groups. This indicates a higher average speed of virtual movement for the digital natives group. For digital natives, a shorter delay was registered before task solving was begun, indicating less hesitation in using a touch screen. The differences in response time, average virtual speed and length of delay at the beginning of solving a task are statistically significant (Tab. 2). An interesting difference between the compared groups is the number of collisions with the terrain (how many times the virtual trajectory crossed the terrain model). Digital natives had fewer collisions in both tasks. It can be hypothesised that less collision may indicate a more intuitive control of the 3D scene, however the differences between the compared groups were not statistically significant and considerable variation existed between individual participants. The differences in other measurements (length of virtual trajectory, rotation, average height of virtual camera) were also small.

Digital immigrants managed to get closer to the searched objects than the digital natives, so it appears that digital immigrants may have been more conscientious in terms of fulfilling the assignment, while digital natives were skewed or unconcentrated when solving tasks and therefore inaccurate. If we convert the success of the approach to a distance between the searched object and the final position of the virtual camera, this difference is not statistically significant. This success in solving the tasks can also be analysed qualitatively. The virtual camera's final position and orientation can be extracted and adequate depictions of the 3D scene as individual participants can then be seen. The spatial distribution of these virtual camera positions can be visualized (Fig. 2) or final views can be reconstructed using interactive tools available online (http://olli.wz.cz/webtest/3dtouchr/visualizations_iccgis2018). Another way of studying user strategy is to replay the movements of individual participants as animations (screen video). This tool for playback is also available online (http://olli.wz.cz/webtest/3dtouchr/visualizations_iccgis2018).

Tab. 2. Results of Mann Whitney test of differences between digital immigrants and digital natives (significance level $\alpha = 0.05$).

		Task 1		Task 2	
		U	p	U	p
Response time [s]		15.0	0.0273	14.0	0.0217
Length of virtual trajectory [km]		37.0	0.7911	39.0	0.9296
Average speed [km/s]		12.0	0.0134	11.0	0.0104
Total rotation [°]	Orthodrome centre angle	29.0	0.3314	23.0	0.1333
	Horizontal (yaw)	37.0	0.7911	27.0	0.2510
	Vertical (pitch)	38.0	0.8598	30.0	0.3772
Average height of virtual camera [m]		23.0	0.1333	28.0	0.2893
Length of delay at the beginning of solving a task [s]		17.0	0.0423	16.0	0.0341
Total duration of individual gestures [s]	Pan	16.0	0.0341	16.0	0.0341
	Pinch	18.0	0.0521	27.0	0.2510
Number of collisions with terrain		35.5	0.6911	31.5	0.4529
Distance to searched object at the end of solving a task [km]		36.0	0.7239	31.0	0.4268

If we focus on touch interaction, the pan and pinch gestures were most often used. Other gestures (press, tap) were used only marginally (negligible length of use). The differences in the total duration of pan gestures are statistically significant, but it is closely related to this gesture being used for a longer time (by both groups). If digital immigrants took significantly longer to solve the tasks than digital natives, then immigrants also used the pan gesture for more time. However, if we focus on the ratio of the use of pan and pinch gestures, we find that the use of the pan gesture is more pronounced for digital natives (in both tasks), whereas for digital immigrants, the ratio of gestures is more balanced.

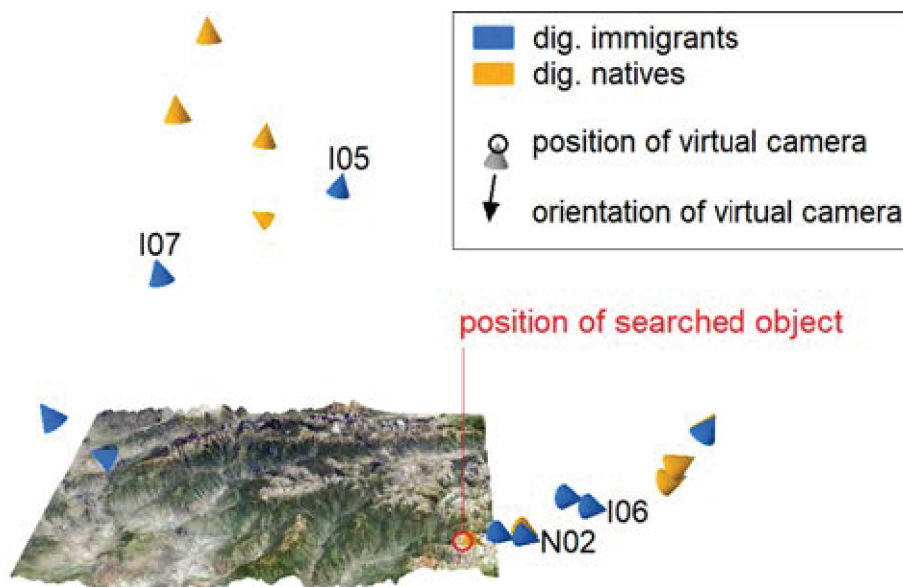


Fig. 2. Final virtual camera positions of individual participants in Task 2.

The directions used with the pan gesture on screen were also analysed (Fig. 3). Only one statistically significant difference appeared between digital natives and digital immigrants (in the second task), which was to pan right in Task 2 (Mann-Whitney test; significance level $\alpha = 0.05$; U: 8,0; p: 0,0047). This difference is mainly due to three participants (I05, I06, I07) using a similar strategy and rotating the terrain in one direction (from left to right) without being able to find the object for a long time. I05 and I07 did not even come close to it (Fig. 2).

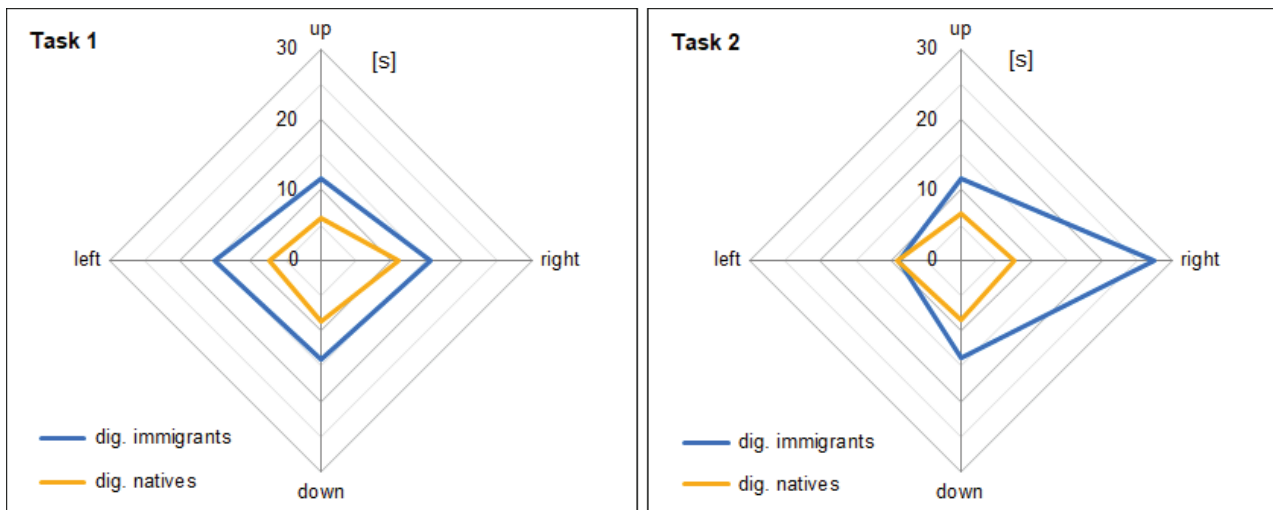


Fig. 3. Average time spent in individual pan gesture directions.

Generally, most of the digital immigrants (7 out of 9 in Task 1 and 8 in Task 2) had a similar strategy. They turned the terrain to the left or right (always predominantly in one direction) and sometimes used a pinch. Digital natives were much more varied with pan gesture direction and therefore, on average, the proportion was more balanced, but they used the pinch gesture less. Subsequent interviews revealed that the participants lacked the means to drag the terrain.

DISCUSSION AND CONCLUSIONS

The two compared user groups (digital natives and digital immigrants) behaved differently when controlling 3D geovisualizations via a touch screen. The main differences can be seen in average response time, speed of virtual movement and length of delay at the beginning of solving a task. A significant difference was also seen in the average duration of use of the pan gesture, but this is due to it being the most frequently used gesture and therefore related to response times. The pan gesture was also analysed with respect to its direction on the screen, which also highlighted a significant difference. Digital immigrants (especially three of them) used significantly more pan towards the right in the second task. One of the possible explanations could be that as they were right handed persons and therefore showed a preference for the direction towards the right. This did not influence any of the digital natives.

Other observed differences were not statistically significant, but they could be addressed in further research (user testing). This is especially the number of collisions with the terrain model. Digital natives had fewer collisions, which could indicate more accurate control of the 3D geovisualization. The two compared groups also differed in gesture strategy. Digital immigrants preferred panning to the left or right, always primarily in one of these directions and sometimes using pinch, whereas digital natives varied the direction of pan gesture more while using less of the pinch gesture.

The main limitation of our research and the current version of the 3DtouchR is only being able to support a limited number of gestures. This will be considered when the following version of 3DtouchR is prepared for the purposes of other experiments. Although the observed differences between digital natives and digital immigrants were significant, care must be taken when generalizing the results due to the relatively small number of participants and tasks. The experiment described in this paper can be considered a preliminary study. Increasing the number of respondents and the variety of tasks would be possible, inter alia, by remote testing (via the internet). In this case, however, controlled testing conditions were lost. At the same time, it is also necessary to optimize 3DtouchR to run correctly in other web browsers, which is crucial for future studies.

Several participants mentioned in the questionnaire that they did not have the means to move the whole terrain (drag) and change the centre of the terrain's rotation (orbiting centre). It would be therefore convenient to implement this possibility for more convenient control of interactive 3D geovisualizations with touch screens. A suitable gesture for this purpose could be, for example, the movement of three fingers on the touch screen. The need to add this type of movement (gesture) may be related to the type of task ("object search") and to the relatively large spatial extent or severity of the terrains used as stimuli. In our previous study (Herman et al., 2016), only similar gestures were supported, but smaller terrain models and other task types ("visibility of objects from mountain peaks") were used and none of the participants mentioned the lack of ability to drag the terrain. It is clear that the support of different gestures differs according to the specific technology used for 3D geovisualizations, as the previous analysis shows (Herman et

al., 2016). Nevertheless, the meaning of certain gestures follow some routines, despite the connections between gestures and actions still not having been standardized, especially in the case of more complex gestures. Therefore, we firmly believe that in 3D geovisualizations where touch control is expected, it is necessary to supply a description of supported gestures and respective actions. We also think that for interactive 3D geovisualization generally, it is advisable to use navigation aids such as overview 2D maps, artificial horizons or a north arrow (the use of some navigation aids is described, for example, by Herman and Řezník, 2015). Our results are relevant for example for deploying interactive 3D geovisualizations on tablets or other touch screen devices in the field of crisis management, geography education or landscape management.

ACKNOWLEDGEMENTS

This research was created in scope projects “Influence of cartographic visualization methods on the success of solving practical and educational spatial tasks” (Grant No. MUNI/M/0846/2015) and “Dynamic mapping methods focused on disaster and risk management in the era of big data” (Grant No. LTACH-17002) and funded by project “Integrated research on environmental changes in the landscape sphere of Earth III” (Grant No. MUNI/A/1251/2017).

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