

Natural interaction with large map interfaces in VR

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ABSTRACT

Location based services are a common application scenario in mobile and ubiquitous computing. A major issue with map applications in this domain is the limited size of the display, which makes interaction and visualization a difficult problem to solve. With the increasing popularity of VR and AR systems, an opportunity exists for map-based applications to overcome the limitation small display sizes, as the user's information visualization space can extend to her entire surroundings. We present a preliminary investigation into how interaction with such very large display interfaces can take place, using a virtual reality headset as the sole input and interaction method.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; • **Human-centered computing** → **Gestural input**; • *Human-centered computing* → *Mixed / augmented reality* • *Human-centered computing* → *Mobile devices*

KEYWORDS

Augmented Reality; Virtual Reality; Map-based applications; Digital Maps; Interaction; Large Interfaces

ACM Reference format:

I. Giannopoulos, A. Komninos and J. Garofalakis. 2017. Natural interaction with large map interfaces in VR. In *Proceedings of 21st Panhellenic Conference on Informatics (PCI)*, 6 pages. <https://doi.org/10.1145/3139367.3139424>

1 INTRODUCTION

Digital maps used on desktop computers in geographical information systems or web-based location services have been studied for their usability for considerable time [1, 3, 13]. In addition to interaction with traditional methods (e.g. keyboard and mouse), non-standard interaction (e.g. gestural, and multimodal input) has also been the focus of study, in an attempt

to improve the usability and interactivity of maps [4, 12]. Mobile maps require careful design to ensure the usability, mostly because of the limited screen area available and the richness of the information that needs to be displayed [7]. Some of the problems during interaction with mobile maps arise from the limited display area, which results in the need for frequent interaction and manipulation of the displayed information. Mobile maps need to be frequently zoomed and panned to gain a thorough spatial understanding [8, 11]. Another frequent problem is the display and selection of markers denoting points of interest (POIs), which are often difficult to select by tapping due to their small size, or due to overlap when POIs are clustered together [5]. The small display size compounds the off-screen POIs visualization issue and hinders understanding of the spatial relationships between on and off-viewport information [2].

By pairing mobile displays with sensors like GPS, accelerometers, magnetometers and inertial gyroscopes, an application can be made aware of the user's position and direction of view. Thus it can provide the user with information that is spatially relevant to their field of vision. This concept of augmenting reality is typically implemented with the superimposition of digital spatial information on camera video feeds, on the screens of mobile devices. These devices could thus be used as a "magic lens", through which the user can experience augmented views of the real world surrounding them [9]. Of course, this method of interaction requires the user to hold their devices at eye-level, which may be tiring during prolonged use, and also does not overcome the problem of the limited size of the information space presented to the user, as the digital information is only visible through the narrow keyhole of the mobile device screen. Augmented reality environments have been found to be tied with regard to usability criteria compared to standard mobile maps and still have several issues to be resolved [6]. In recent years, interest and advances in wearable display technology including augmented reality and virtual reality headsets, have resulted in freeing up the user from the constraints of the mobile screen, by extending the available information space to the entire world around the user. The use of head mounted displays (HMDs) increases the space upon which digital information can be displayed to the entire field of view of the user, minimizing the need for frequent interaction (e.g., panning) and results in more natural interaction, consistent with everyday experiences (i.e. users simply turn their heads towards the location where the information they need might be found).

As such, the use of AR or VR headsets to explore large information spaces, like maps, can offer a more natural and comfortable way to afford users a better spatial understanding of information. However, the use of such headsets requires a different approach to designing interaction and input, compared to the touch-based mobile screens, or keyboard and mouse used

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PCI 2017, September 28–30, 2017, Larissa, Greece

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ACM ISBN 978-1-4503-5355-7/17/09...\$15.00 <https://doi.org/10.1145/3139367.3139424>

when exploring maps on large screen desktop computers. The only relevant paper covering use of maps with an HMD is by [10], however in this paper the authors evaluate a limited set of gestural design for map control, focusing solely on zooming and panning. Our paper therefore focuses on addressing the issue of controlling very large maps displayed via headset technologies, by exploring how different gestural or limited hand-input modalities can be mapped onto actions related to the control of digital maps and the information objects presented in these.

2 DESIGNING MAP INTERACTION FOR HMDs

To explore the interaction with maps in a HMD use context, we proceeded with the design of an application using the Samsung Gear VR headset (Figure 1). This is a VR HMD in which a smartphone is inserted at the front of the accessory, effectively making the device screen act as the VR display with 3D vision effects such as depth perception. The smartphone's embedded sensors are used as input to the applications running on the smartphone, allowing the device to accurately know where the user is looking and therefore adapt the displayed views to provide an immersive VR experience. The system also has further input options via a touchpad surface on the right side of the HMD, as well as a programmable "back" button and volume buttons near the touchpad.

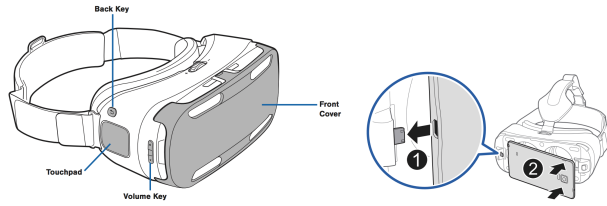


Figure 1: The Samsung Gear VR accessory, showing the placement of the input controls and smartphone.

For the purposes of our experiment we developed an application for Android using the Unity IDE, which renders a very large map area in front of the user. The map is dynamically populated from the OpenStreetMaps API. The application also displays points of interest as map markers. The map extends beyond the user's lateral field of view, as shown in Figure 2.

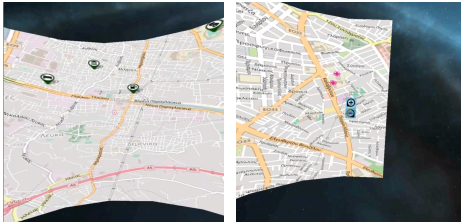


Figure 2: The map application demonstrating the size of the map, which extends beyond the user's lateral FOV.

We then proceeded to design the interaction with the map itself, by considering the core functions that a digital map should offer and how they might be mapped to the input modalities afforded by the Gear VR device. We therefore considered two main interaction techniques: A hybrid technique incorporating touch and button controls with natural head movement, and an all-gestural (virtual) technique consisting solely of head

movements. In all cases the user is presented with a red circular reticle at the center of her FOV, that acts as a "pointer". By placing the reticle over the various map controls (gazing), the user can perform input actions with these as will be described.

The map actions that we designed for are as follows (Table 1): Panning the map, zooming (in and out) of the map, hovering over a POI to obtain a tooltip and selecting a POI (a common action used to bring up more detailed information). Panning, zooming and selecting are actions available on all desktop and mobile maps, while hovering is an action available on desktop maps and augmented reality spatial applications. For panning we note here that a user is able to pan horizontally, vertically or diagonally by gazing the four edges or corners of the map.

Table 1: The input modalities in the TH and Virtual input methods

	Panning	Zooming	Hover	Select
Tactile hybrid	Tap & hold + head movement	Double tap or double click on back button	Gaze on POI	Tap on POI
Virtual	Gaze on map edges	Gaze on zoom buttons	Gaze on POI	Continue to gaze on POI after hover

We considered the concept of delays between preparing to perform an action and issuing the relevant command. On tactile controls (e.g. a mouse, or the Gear VR buttons), a user can rest their finger on the control element in preparation to perform an action, without actually performing it, using a light touch. This allows users to change their mind before committing the command. For the gestural interface we considered introducing a short delay between gazing and the registering of a command, in order to afford the users the ability to change their minds or avoid unintended interactions. Feedback during interactions is also an aspect which we considered as important. When using a touch (or tactile) interaction, primary feedback is immediately available to the user that they have provided an input command correctly (e.g., a user can feel their fingers resting on a button before it is pressed and when it is clicked – the same applies also to touch areas). Further feedback is provided when the system performs an observable action, therefore indicating that the input command was successfully registered. On purely gestural interfaces however, this primary feedback is normally lacking as there is no way that a user can know that the input command has been performed, until they observe some effect taking place on the interface. Hence we designed a mechanism to provide this feedback to users by displaying visual cues that an input command was being registered prior to being enacted. This was implemented by providing some feedback to users, in the form of gradually fading in panning visual indicators or using a loading bar on the zoom icons and POIs (e.g. see Figure 3).

As a result, we ended up with four method designs that incorporated the following interaction elements (Table 2):

- Tactile hybrid vs. gestural only control
- Delay or immediate action (for gestural only)

- Delay feedback or no feedback (for gestural only)

Table 2: The designed control methods

Interface	Delay	Feedback
Tact. Hybrid (TH)	-	-
Virtual 1 (V1)	-	-
Virtual 2 (V2)	X	-
Virtual 3 (V3)	X	X

For the Tactile Hybrid (TH) interface we did not implement delays or feedback on the interface, since the primary feedback is achievable via the tactile sensation and the user is able to postpone a primed action until ready to commit to it, by resting their hands on the controls. For V1, there is no delay in an action when the reticle is moved into a control area of the display. Thus, feedback about the impending input is pointless to implement, since it occurs immediately. Interfaces V2 & V3 are similar with the exception that in V2, no feedback on the impending action is provided (after a short delay where nothing changes in the interface, the input command is enacted). In V3, visual feedback of the time elapsed during the delay is provided (Figure 3).



Figure 3: V3 feedback implementation: The progress bar on zoom controls (top left) & POIs (hover and then select – middle and bottom left) and the fade-in of the panning controls in the delay with feedback interface (right)

The delays in V2 and V3 are set empirically to 750ms to provide a reasonable balance between quick system response and opportunity to reconsider an action. Additionally, for the zoom buttons in V1-3 we implement an delay of 500ms in case the user gaze persists on the control area, to prevent the continuous zoom in/out (simulating thus the time elapsing between successive double-taps/clicks used for zooming in the TH interface). Finally, we added a logging mechanism in our application which captures the timestamped interactions of the user with the application (scrolling, selection, hovering, zooming).

3 EXPERIMENTAL EVALUATION

We proceeded to perform a laboratory experiment with the above interfaces, where we attempted to evaluate participants'

performance using all four interfaces and the map control options (panning, zooming, hovering, selecting) in each. We recruited 25 users who were all Computer Science students, aged 18-30 (12 female). For this purpose, we randomly assigned an interface order to each participant, and with each interface the participant was asked to perform four tasks – One task related to identifying and selecting POIs (all other controls disabled), one to panning (starting from a given location and following map features, e.g. roads or railway lines to find another location, zoom controls disabled), one to zooming (continuously zoom in/out until a map feature is visible, panning disabled) and a combination task which included zooming, panning and identifying/selecting a POI. The order of the first three tasks was random, and the combination task was always last. Each task was performed once, under a scenario chosen randomly from four different but similar scenario options, which were developed carefully so as to correspond to an equal number of required actions by the participants. An example for each of the four scenarios for each task is as follows:

POI selection task: Select the markers named Gas Station 1, Hospital 2 and Hotel 2 in any order.

Panning task: Follow the railway line in a south-west direction until you find the St. Andrew's railway station. Then select the station marker.

Zooming task: Use the zoom-in command repeatedly until the label "Flisvos Square" appears on the map.

Combination task: Starting at the center of the map (George Square) and moving along the traffic direction on Corinth Street, select the marker positioned on the first intersection with a street whose traffic direction is towards the right of Corinth Street.

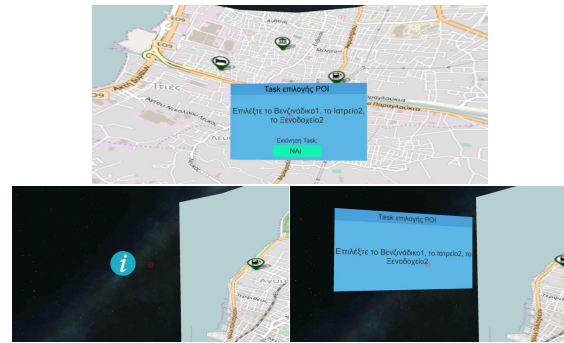


Figure 4: Participant instructions prior to beginning a task (clicking the green button begins the task) (top). A help button is available off the left side of the map (bottom)

The participants were given explicit instructions on how each interface operated and then allowed some time to freely interact and familiarize themselves with the interfaces prior to a set of tasks. Participants began actual testing when they reported they felt ready. Instructions for what to do during a task were presented on-screen and there was also a "help" button located to the left of the map area which, if hovered on, showed a modal dialog with the current task instructions, to help in case participants forgot the instructions (Figure 4). After the completion of a set of tasks with each interface, the participants filled in a NASA-TLX questionnaire and continued to the next set

of tasks with another interface. At the end of the experiment, participants were given a final set of subjective questions.

4 EXPERIMENT RESULTS

All results are reported using appropriate tests, based on the normality of the data distribution (Shapiro-Wilk). Outliers from the data are also removed where appropriate for analysis.

4.1 Quantitative Results

In the following section we will present first the analysis of the three tasks focused on individual tasks and then proceed with the description of user behaviour during the complex combinatory task. The following figures (5 and 6) show the number of actions and time taken to complete each individual task by participants.

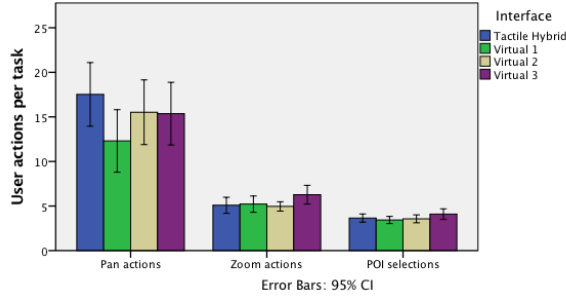


Figure 5: Panning, zooming and POI selection per task

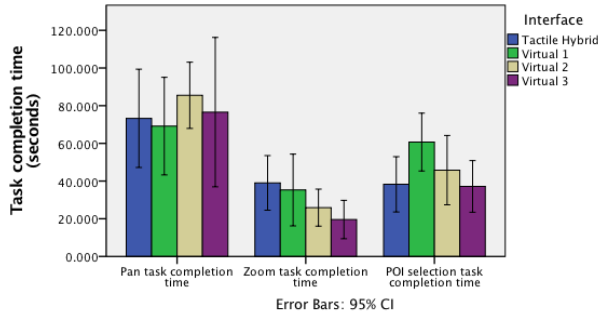


Figure 6: Time taken to complete panning, zooming and POI selection tasks

4.1.1 Panning task: In the panning task, a Friedman test reveals that a statistically significant difference exists in the number of pans required to complete the task ($\chi^2_{(21)}=9.768$, $p=0.21$). Though the number of pans to complete the task appears to be greater in the Tactile Hybrid method, post-hoc Bonferroni-corrected pairwise Wilcoxon signed rank tests between all combinations do not reveal any statistically significant differences in the data. With regard to the time taken to complete the panning task, a Friedman test does not reveal any statistically significant difference either ($\chi^2_{(21)}=5.629$, $p>0.05$). We conclude therefore that none of the methods demonstrated any advantages.

4.1.2 Zooming task. In the zooming task, a Friedman test reveals that a statistically significant difference exists in the data ($\chi^2_{(22)}=10.2$, $p=0.017$) regarding the task completion time. However, post-hoc Bonferroni-corrected pairwise Wilcoxon signed rank tests between all combinations do not reveal any

statistically significant differences in the data. We further proceeded to analyse the number of zoom actions – here it is worth bearing in mind that our tasks required 4 zoom in or zoom out actions as a minimum, hence a larger number indicates a non-optimal performance. In this case, a Friedman test revealed no statistically significant differences ($\chi^2_{(24)}=6.335$, $p>0.05$). As such, no method shows advantages in the speed of completing the task or in the number of actions required to do so.

4.1.3 POI selection task. In the POI selection task, a Friedman test reveals that the time taken to complete the tasks did not have a statistically significant difference across the methods used ($\chi^2_{(21)}=6.257$, $p>0.05$). This is an interesting finding since we would have expected that the introduced delay in methods Virtual 2 & 3 would have increased the time taken to complete this task. The participants were instructed to select 3 POIs in each task and an analysis of the actual number of clicked POIs with a Friedman test showed that there were no statistically significant differences, albeit marginally ($\chi^2_{(23)}=7.441$, $p=0.059$).

4.1.4 Combination Task. In terms of time required to complete the task (Figure 7), a Friedman test reveals no statistically significant difference between the four interfaces ($\chi^2_{(23)}=0.652$, $p>0.05$).

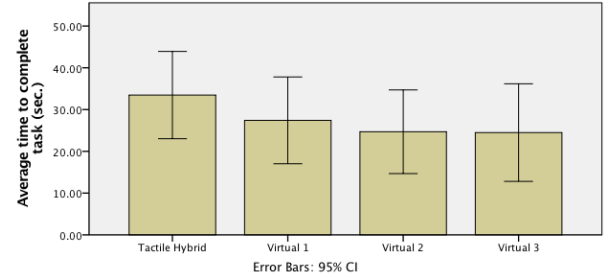


Figure 7: Time taken to complete the combinatory task

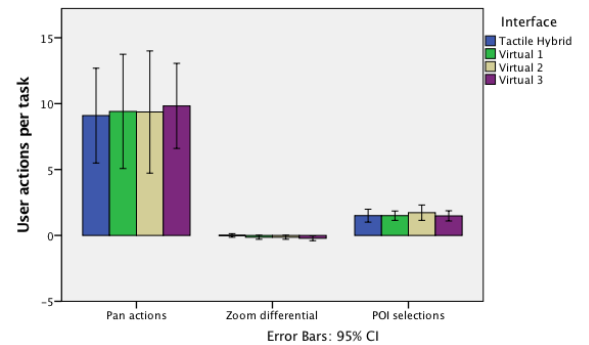


Figure 8: User actions during the combinatory task

With regard to user actions during the combination task (Figure 8), our analysis proceeded as previously, though, here, we did not consider the absolute number of zoom actions performed by the user, but instead the differential between zoom in and zoom out actions, by subtracting the relevant values. A negative value indicates the participant performed more zoom-out than zoom-in actions, while a value of zero means that the participant performed zero, or an equal number of self-cancelling actions (hence keeping the zoom level equal to the starting condition). A

Friedman test reveals no statistically significant differences in the zoom differential of the map interface ($\chi^2(24)=1.581$, $p>0.05$). The same type of test reveals no statistically significant differences in neither the number of pan actions ($\chi^2(24)=0.664$, $p>0.05$) nor the number of POI selections ($\chi^2(24)=1.539$, $p>0.05$).

4.1.5 Summary of results. With the above results in mind, we are guided to the conclusion that the differences in the interaction and control elements of the user interface methods did not affect the participants' performance. The addition of visible feedback and artificial delay time (whether the feedback was visible or not) did not appear to delay the participants in completing tasks. This observation may have multiple explanations but we believe it is plausible that the participants may have introduced their own "delay" time in TH and V1, by pausing to think more carefully before committing to an action, while in V2 and V3 they could act in a more carefree manner, since they could always change their mind before an input command was effected.

4.2 Qualitative Results

Following the completion of tasks with each method, we issued a NASA-TLX questionnaire to each participant (scaled 0-100 in increments of 5 units). Data from the NASA-TLX questionnaire did not exhibit any outliers so there was no need to filter any cases out of the analysis (Figure 9).

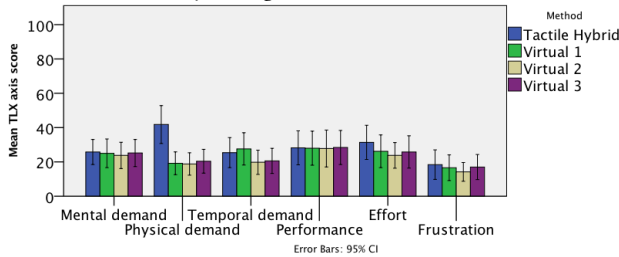


Figure 9: NASA-TLX results

4.2.1 Mental demand, Performance, Effort and Frustration. Friedman tests revealed no statistically significant differences in any of these factors (Mental demand $\chi^2(25)=0.816$, $p>0.05$; Performance $\chi^2(25)=3.211$, $p>0.05$; Effort $\chi^2(25)=7.188$, $p>0.05$; Frustration $\chi^2(25)=1.942$, $p>0.05$).

4.2.2 Physical & Temporal demand. In terms of physical demand, a Friedman test reveals a statistically significant difference across the methods ($\chi^2(25)=22.415$, $p<0.01$). Post-hoc Bonferroni-corrected Wilcoxon signed rank tests, reveal statistically significant differences between Tactile Hybrid and all Virtual methods (TH-V1 $Z=-3.599$ $p<0.01$, TH-V2 $Z=-3.650$ $p<0.01$, TH-V3 $Z=-3.534$ $p<0.01$), showing that the Tactile Hybrid method was perceived as the most tiring method due to the combination of manual and head motor control required.

A Friedman test reveals statistically significant differences in the temporal demand perceived by participants ($\chi^2(25)=10.728$, $p<0.05$). Post-hoc Bonferroni-corrected Wilcoxon signed rank tests, reveal statistically significant differences only between methods Virtual 1 and Virtual 2 ($Z=-2.730$, $p<0.01$). This is a counterintuitive result, because we would have expected that users would notice the addition of delay time (V2 and V3). Although we saw that task completion time did not actually

differ in our quantitative analysis, this result aligns with our assumptions that participants in TH and V1 probably added their own "delay" by pausing to think before committing to an action, and this additional burden was more noticeable to them compared to the system-introduced delay. Finally, the addition of visible feedback along with the delay (V3) seems to raise the perceived temporal demand for participants and thus its use should probably be avoided, unless it serves a specific purpose.

4.2.3 Appropriateness of the map size. At the end of the session, we asked participants for their opinion about the size of the displayed map area on a 5-point Likert scale (1=very small, 3=about right, 5=very big). Participants were asked to imagine that they might have this service available to them as an application during daily use while navigating an unfamiliar city. 88% of participants responded that they felt that the map was about the right size for this purpose, while the remaining 12% felt that the map could be classified as "big".

4.2.4 Subjective preference of individual map controls. We further asked participants to reflect on the map control options of each method, and rank the different options by assigning their preferred order of preference for each control option (Figure 10).



Figure 10: Results of the rating of control methods

First, we asked them about their opinion of the zoom functions. For this, most participants (40%) placed the "Delay & Feedback" (V3) option in 1st place of preference, followed by the "No Delay" (V1) option (32% of participants). With regard to the hover function (displaying a tooltip prior to selection), 80% of participants placed the "No Delay" (V1) option as their 1st preference, followed by "Delay & Feedback" (V3) which 16% of participants preferred most. With regard to selecting a marker (POI) on the map, participants were tied between placing the "No Delay" (V1) and "Single Tap" (TH) option as their 1st preference (36%). However, the "Single Tap" option was rated 2nd by 28% of participants while the "No Delay" option was rated 2nd by 24%, so the "Single Tap" is considered as marginally preferable. Finally, with regard to panning, the "No Delay" (V1) option was rated as most preferred by 84% of participants, followed by "Delay & Feedback" (V3) (12%). Participants liked the combination of tap & hold combined with the head gesture option the least.

4.2.5 General User feedback. We also asked users' feedback on what types of application they thought the use of large maps would be appropriate for. Twelve participants provided some ideas. Four participants stated that they felt this application would be good for educational purposes (e.g. teaching children

geography, or to help students explore the spatial distribution of information on a subject). Three participants felt this application could replace mobile and desktop maps in services of any kind. One further participant indicated that this application would be useful for tourism applications only. Finally, two participants felt it would benefit users with special needs (limited motor control) and one stated the large map would be good for gaming.

As a last question, we asked participants to provide feedback on changes they would like to make to the application and received responses from seven participants. Most comments reflected the operation of the interface (e.g. where controls should be placed or different combinations of control methods, as indicated in the order of preference in the previous questions). We highlight however the comments of two participants, one of whom felt that the control methods could also benefit from spoken instructions (voice command recognition) and a further participant who believed that the application could be supplemented by hand/arm gesture recognition.

5 DISCUSSION AND FURTHER WORK

The outcome of this subjective evaluation highlights some interesting findings. First, the combination of hand and head input appears to cause tiredness to the users, which is understandable as the tactile area is not visible and thus the arm needs to be constantly positioned appropriately in order to maintain the ability to quickly find the input areas (touchpad & buttons). Additionally, the introduced delays between actions in the virtual conditions do not seem to cause any significant overall delay or frustration in the users' ability to complete tasks. We hypothesize that this is because the delay affords users the ability to prevent and correct inadvertent input, thus requiring less actions to correct it. Finally, the breakdown of user preference by individual map control rather than the entire input reveals that delay, visual feedback and simple touch gestures can play a role in designing a better control method for large AR/VR maps, though each technique has to be carefully applied to individual controls and not over the entire interface. In summary, we suggest the following preliminary guidelines for designers of interaction with large information spaces which apply to VR maps but can be extended to other application interfaces:

Head movement for input is natural and effective: The use of natural interaction such as head movement and gaze for cursor control is easy to learn and does not tire participants, hence a UI supporting complex interaction can be designed without the need for external input mechanisms.

Avoid external tactile controls: External input mechanisms in VR do not hinder performance but are found to be tiring for participants. Clearly here the reliance on tactile sensation to find and manipulate the controls places an additional and needless burden on users, hence interfaces should be designed for taking maximum advantage of head and gaze tracking only.

Implement artificial delays where the resulting action re-renders large parts of the interface: Artificial delays in between the issuing of an input command and its execution have to be strategically used and paired with visual feedback to users. In our example, the zoom action (in which participants rated delay & feedback as the most desired mechanism), the command has a high cognitive impact because the entire interface and the

information in it are rendered from scratch. An inadvertent zoom requires the user to rebuild their understanding of the information displayed and its spatial relationships. In all other cases (panning, selecting a POI, hovering), these relationships are largely maintained, hence the users don't need artificial delays.

In further work, we aim to re-design the control interface according to these findings and evaluate it in a laboratory and field setting, using AR instead of VR technology, and to examine how these guidelines apply to other types of VR/AR applications that could benefit from large interfaces (e.g. navigating large collections of photographs, watching videos, file and information management, viewing architectural and design drawings). Further work should also investigate performance in mobile settings (e.g. in situations like public transport), which may introduce problems during the hand or head gesture controls and highlight issues in resolving input uncertainty.

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