# Towards closing the near/far domain gap: Adding tactile interface elements to an immersive visualization interface

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## ABSTRACT

This paper investigates the use of tactile elements within an immersive visualization interface, to determine if the level of immersion can be increased by integrating different domains (near/far/control), as defined in head-up display (HUD) theory [20]. A novel interface, implemented in a 3D Virtual Reality application, combines tangibles, a passive tactile surface, tracked hands and gaze. The goal is to allow the user navigation, selection (both near and far), manipulation and system control without the requirement for switching modes. The interface and interaction techniques are deployed within an immersive analytics application that renders procedurally generated 3D geometry and 2D chart graphs, embedded in an explorable environment. Improved legibility of the content displayed at different angles, at a distance and up close, was also achieved thanks to the development of novel interaction techniques.

A mixed methods evaluation was employed, combining expert evaluation of the prototypes, formal task analysis and interviews to get an initial indication of the potential of tactile elements and near and far interaction in a VR visualization environment. Results suggest the application is a valid case study for hybrid visualizations of data displayed on 2D panels in a 3D environment, using head worn displays. It allows multimodal interaction with the data, both up close and at a distance, with tactile feedback, and a non cluttered control space. Improved legibility of content, and a reliable navigation technique were also noted in the evaluation.

## CCS CONCEPTS

• **Human computer interaction (HCI) → HCI design and evaluation methods → Walkthrough evaluations**

## KEYWORDS

3D Interfaces, Interaction Techniques, Immersive Analytics, Evaluation

## 1 INTRODUCTION

Current research in immersive technologies for visual analytics examines the place of VR and large displays as platforms for data visualization and analysis. Some results [15] indicate that head worn displays (HWD) can perform on par with large CAVE installations in specific domains.

As advances in technology bring about many new possibilities for the development and design of such interactive visualization techniques, the possibility of creating a tactile user interface for a visualization & analytics environment that is immersive, real time, interactive and accessible by many, is now feasible, outside of dedicated labs, and with off-the-shelf hardware components.

One of the research questions that this pilot study tries to address in terms of immersive analytics is the possibility of using hybrid 2D/3D visualizations in an explorable virtual environment, it also addresses how best to interact with them at a distance and up close.

Real Time 3D engines can be used, combined with virtual reality HWDs, for the design of large simulated environments, where existing visualization techniques, both 2D and 3D, can be displayed alongside or integrated with high definition media content, in spatially partitioned environments such as data worlds: Virtual Office/ Gallery/ Terrain/ Abstract Space.

Integrated tactile objects, combined with aligned 3D props, shaded and animated in virtual space, coexist with various forms of 2D user interfaces (UI) to enhance interaction with audiovisual media and visualizations in traditional heads up display, tightly embedded in the environment itself, in the far domain, or in the user's peripersonal space, the near domain.

Markerless tracking of the user's entire figure, or of specific body parts such as arms and hands, also presents challenges and opportunities for embodied interaction in such spaces. This allows the user to overcome the loss of proprioceptive clues in VR alsol aiding interaction and collaboration (both co-located and at a distance), by displaying high fidelity representations of the body in the Virtual environment.

## 2 MOTIVATION

The main motivation for this pilot study was to demonstrate an interactive visualization solution in VR, using game engine technology and off the shelf hardware. This was aimed at building a pilot study towards achieving a baseline for interaction and visualization in an immersive analytics framework. Some of the considerations engaged during the development of the case study, attempting a multidisciplinary approach, combining taxonomies from 3D interaction and visual analytics, are listed below

### 2.1 Hybrid data Visualization

The visualization of data in an immersive environment presents a challenge. It requires the use of existing visualization techniques and of immersive environments for context, organization, linking, and novel interaction techniques. Data can be accessed, filtered, rearranged and presented in a data-world environment, with careful considerations on data formatting, scrubbing, filtering and reliability. The simulated environment itself, generates vast amount of metadata which can be visualized, within the application, to provide insights and further analysis by leveraging existing tools.

### 2.2 Multimodal Interfaces

Integrated touch, gaze and gesture interaction is no longer solely theoretical possibility, but current and affordable. Fused modalities with ad-hoc dedicated tangible and tactile hardware interfaces allow for multiple case studies, controlled redundancy, greater accessibility and accommodate various levels of user expertise for different stakeholders.

### 2.3 Interaction techniques

Post WIMP interaction is coming of age with emphasis on visualization spaces. New studies, taxonomies and experiments to inform practice, alongside considerations on the role cognition plays, need to be addressed: natural user interfaces, task oriented design, embodiment, automatic methods, affordances and signifiers.

### 2.4 Ergonomics

Considerations on ergonomics for such solutions: room scale vs seated, gesture fatigue, controls layout, tactile feedback, proprioception in an occluded VR environment, are intrinsic to the use of VR. Each problematic, taken individually, is being tackled somewhat by research. While not directly addressing these in this study, the challenge is to fuse insights from different disciplines to create a comfortable interaction solution for immersive analytics.

## 3 RELATED WORK

Different Taxonomies for data visualization and interaction have been about for some time [1], more recently the 4 dominant tasks to be addressed by 3D interfaces are defined as navigation, selection, manipulation and system-control [2], this was the starting premise for the design of an application that would combine both visualization and 3D interaction principles.

In recent times a new approach to immersive interaction, merged with data visualization and analytics developments, has spurred a structured effort to explore the synergy between new technologies and the problems arising from the analysis of large, heterogeneous data sets in an immersive environment as in [3] & [4].

One of the research questions to be tackled within the scope of research as defined in the immersive analytics thrust[5], addressed in [6] using large displays, is how to best handle 2D/3D hybrid visualizations, and interaction techniques for immersive applications. This is addressed by a number of publications [7] [8] [9] in different domains, and is one of the driving factors behind the project presented in this paper.

Similar approaches for navigation and interaction range from the use of touch devices combined with immersive environments [10], to tracking and VR reconstruction of the user body alongside tangible/tactile surfaces, with passive or haptic feedback [11]. The application presented in this study differs in the use of markerless tracking of the user hands, and the use of HWD instead of large displays.

Tangible user interfaces (TUIs) are one of the approaches suggested, with 6 degrees of freedom tactile controllers offering valid solutions to 3D navigation [12]. When considering HWD [13] as opposed to large immersive environments, the user's own body is occluded from view, at least in the current generation of virtual reality headsets. The current generation of HWD's are nonetheless starting to prove valuable for interactive visualization research, with promising results, even compared to larger immersive setups such as CAVE2 installations [14] [15], aiding collaboration and sharing of insights.

Spatial and natural interfaces for interaction are also in continuous evolution. There are many studies which focus on gestures, gaze, lenses and avatars representations[16] and interest in interaction for visualization is constantly growing, with new categories such as collaboration and gamification[17] being added to the canon of interaction in visualization.

Cognitive research within the spatial domain suggests that depth in a 3D volume is a valid tool for spatial searching, and that more studies are required to understand our capabilities in dealing with three dimensional space for visualization, [18] addresses the problem of searching in 3D volumes. An interesting phenomenon addressed by the prototype presented in this paper is known as nearby-hands [19]. By visualizing one's hands in the proximity of an object within interaction space, the precision of the interaction improves. As expressed in research related to the design of HUD for aviation[20] the partitioning of space in a near, far and control domain is highly relevant to problems of attention shifting. How to best address control of navigation, selection and manipulation of interactables in these three domains, without needing excessive change of interaction modality, is yet another challenge worth exploring.

The fields that explore immersive visualization are varied and the list below is by no means complete.

Scientific Visualization: astronomy [21], cellular biology , neurology, computer code visualization.

Life sciences: environmental studies, heritage [22], archaeology, urban planning.

Info Viz: 2D/3D hybrid visualizations, networks, 3D scatterplots and multivariate data visualizations [23]

## 4 IMPLEMENTATION

We're now going to consider the implementation of the application, with specific sections on the tactile components, the virtual environment and the interaction techniques deployed. Details of the hardware and evaluation setup, with discussion and future work are addressed further down.

### 4.1 Tactile UI

The hardware controllers are off-the-shelf products, the components of the interface are divided according to the classic taxonomy of 3D interaction

- 6 degrees of freedom one handed controller for navigation, both translation and rotation
- a rotary button for selection and manipulation
- a passive touch surface for system control.

Inside the application, in Virtual Reality, dynamic 3D props are displayed to represent the spatial position of the hardware controllers, initially calibrated using the tracked hands, to appear at the correct location in virtual space. Hand Tracking was achieved via a head mounted sensor and the provided API, using the manufacturer provided interaction library.

The controller representations are animated and respond to interaction with the hardware to give feedback of usage as well as tactile feedback on contact. The users' hands are tracked at all times and hand representations are displayed in the application, to both help in the use of the hardware controls, and for pointing and selection techniques. The user can choose either gaze and a hardware button or the tracked hands pointing with a pinch gesture to engage in the far domain, or direct touch of interactables with the virtual hands in the near domain. Merging of gaze, hand pointing, and direct touch techniques was achieved in a custom solution for this project.

The touch surface is achieved by aligning the system control UI canvas in VR space with the real world position of the dedicated surface during the calibration phase. Hand and finger tracking are used to interact directly with the virtual UI canvas and the user gets tactile tap and slide feedback in the real world for the control domain.

The 2 controllers are positioned on infrared absorbing flat surfaces to improve contrast and therefore tracking precision, the touchpad is made using the same material.

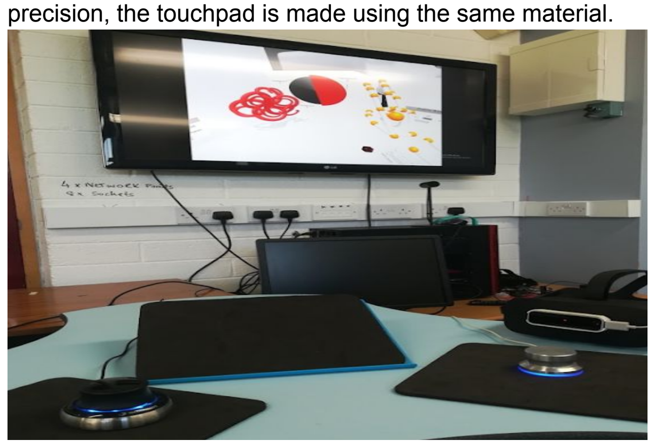

Figure 1 A Close up view of the interface and environment

As discussed all 3 tactile devices have a representation of their position and state in the virtual space, with the hand tracking solution allowing the user to find the controllers after performing free hand gestures, thus augmenting proprioceptive perception of the desk space in front, and assisting in understanding tools affordances, while also giving feedback when the controllers are being used. These representations are local to the user coordinate system, as are the hand representations, they are constrained to the users close space effectively following her during navigation

### 4.2 Virtual Environment

The application also consists of an explorable 3D virtual environment divided in 3 distinct areas, an initial "walled" partition, resembling a virtual office space, made of simple primitives in off-white shading. Here the bulk of the 2D and 3D visualizations are displayed. This area leads via a corridor to a separate area, with more complex, organic, spatial partitioning, resembling a cave. Here the user interacts with more 2D canvasses, and fewer 3D visualizations. Finally, the space surrounding these two environments, is also accessible by the user for an overview.

Some external libraries were used in the software implementation. A separate asset creation software called Structure Synth was used to generate the 3D visualizations. These are based on recursive rules and procedurally generated by the software offline using the eisenscript language. They're then exported to obj format, and imported into the scene with engine tools, at varying scales, from ornament size to very large.

### 4.3 User Driven Interaction

Viewing of the accompanying video [22] is recommended as the deployed interactions are strongly interlinked and were designed working as a whole.

Navigation is based on available functionality provided by the 3D mouse hardware manufacturer, implemented in the application as a variable speed 3 axis of translation by 2 axis of rotation technique (roll is turned off by default for user comfort), with variable speed.

Gaze interaction is based on HWD head tracking and ray casting is used as one method to point at relevant objects: a cursor is displayed on any 2D canvas if these are being looked at, the cursor scales with distance to remain visible on far elements and not overwhelm a close one.

As long as the user is looking at a specific canvas, the cursor will track gaze over the canvas, highlighting sub-elements on the canvas such as text, button/sliders, or elements of a 2D visualization. Highlighting of these elements occurs when the 2D projected cursor enters the elements 2D collider, this can also trigger events on a linked 3D visualization. A similar cursor is displayed if the user lifts their hands off the controllers, activating hand pointing at a distance with pinch gesture used for selection. On proximity with a 2D visualization, "in air" touch is available, using the same technique for system control explained below.

The single rotary button controller allows for selection of elements and activation of a UI button pointed by gaze, by the user pushing down on it. Manipulation of a number of parameters on the selected element of a canvas is achieved by spinning the single rotary controller in either direction after a button press, for example:

- moving a slider left or right, both on a situated canvas and on the system control panel,
- increasing or decreasing a value for
    - graphs (Bar and Pie Charts)
    - tabular tables of numbers.

The system control panel is currently composed of 3 buttons and one slider. This allows control of the selected parameter with direct touch of the corresponding button. This remains highlighted, and subsequent manipulation of the value is achieved by using the single slider. Text on the panel indicates the current value for each parameter.

The virtual finger collider must intersect with the canvas element collider, to activate the control. As the canvas is aligned with the physical touch surface during calibration, tactile feedback is provided for both button presses and slider control.

At present the three button controls are assigned to:

- speed: a multiplier of the translation speed of navigation
- zoom: a parameter that controls the camera field of view within a range
- lighting: changes the light intensity in the scene within a range.

The single slider below the buttons has changing min and max values based on the parameter to manipulate, and moves to the current value of a parameter on button press. A single slider was chosen so as to avoid clutter in the control space [20].

### 4.4 Automated Interaction

Two novel system initiated interactions were also designed and implemented on all 2D canvases excluding the system control panels, in an attempt to bridge interactions in the near and far domains, and to improve legibility of the content of the panels, while keeping the visualizations firmly collocated in their surrounding space

- "partial bill boarding" : upon the user coming within a specific distance and angular range, in front of a 2D canvas, the panel will rotate on its Y axis using spherical lerp in the direction of the user. A customizable specific max angle is used to limit the range of canvas rotation in order to avoid a canvas placed near environment geometry clipping through it.
- "proximity scaling": when the user approaches a canvas within a specified range, the canvas will begin to scale down by a specified amount, as the user moves closer, starting with normal scale at max distance, and ending at a specified reduced scale at min distance.

These two techniques were designed to improve legibility of embedded 2D content from a wider angle and range, while avoiding the unnatural feeling of a panel always facing the observers point of view, and to allow the user to get in close proximity of a 2D visualization, without losing legibility or being overwhelmed by its size, while keeping the content accessible from a distance. The added benefit of the proximity scaling technique is that it allows comfortable "in air" direct touch interaction upon coming close to 2D panels, in a fashion already familiar to the user in the interaction with the system controls, this occurs naturally upon reaching arm length distance with the automatically scaled panel.

## 5 EXPERIMENTAL DESIGN

This section documents the pilot study, where initial interviews at the design stage with an industry expert from ergonomics, one from user experience design and one from data analytics were carried out to test the implementation of the tactile elements of the prototype, and to inform iteration on design. The three semi structured interviews were conducted informally. The experts were shown the current version of the prototype, followed by a discussion. They then tested the application directly by engaging with it in VR in the presence of the interviewer, performing a series of tasks as prompted. This was followed, after completion of the more formal evaluation described below, by a short debriefing session with each of the experts, to discuss results and future work.

A task based experimental scenario was designed, based on initial expert testing. It combined participant observation with a series of post-test questions relating to the implementation of the prototype interface, which was updated after the expert discussions.

The evaluation was carried out on a Windows 10 PC running Unity3D version 5.61f1 connected to an Oculus Rift CV1 Head Worn Display with a Leap Motion sensor attached to the visor for hand tracking. The interface combined a 3D mouse (3DConnexion Space Navigator) for navigation, a rotary controller for data selection and manipulation (Griffin Power Mate) and a tilted passive touch surface, for system control.

The aim of the scenario was to get participants to use the combined tactile and gestural elements of the interface to perform various tasks. These tasks required the participant to navigate the 3D space to select and manipulate data, alongside evaluating their ability to control the system itself. The tasks aimed to allow a set of questions to be asked relating to the interface design, alongside specifics on the selection and manipulation of data at a distance and up close using the combined tactile and gestural interface.

There are a number of issues that the experiment addresses:

- Whether 2D panels can be successfully embedded in 3D space, both surrounding the user, at arm's length, thus following the user during navigation; and at fixed locations in the environment, far from the user.
- Whether a smooth transition between these two domains is possible, by means of navigating to the panel, or interaction at a distance.
- Whether these panels can remain legible and be interacted with, both at a distance (with gaze pointing and button press, or with hand pointing and pinch gesture) or up close ( direct touch and drag), thanks to the automated interaction techniques described above.
- Whether an uncluttered tactile user interface in the vicinity of the user, operating in a seated position, can comfortably afford all the requirements of 3D interaction in the near and far domains in VR, and offer relevant feedback to the user of the activation of the hardware controls it represents
- Whether the combined use of tactiles, gaze, gestures and in air touch, for selection and manipulation of data visualizations complement one another or not.

All tests were carried out in a dedicated room using the equipment detailed above (Figure 2):

Figure 2 A view of the setup during testing

All participants were given an introductory demonstration that covered navigation, data selection/manipulation and system control to ensure that they were familiar with the operation of the interface. They were then asked to perform a short series of tasks using the interface relating to the querying of data in the 3D environment:

**1. Introduction to the interface** the participant is given guidance through some demonstration visualisations, to ensure they understand the controls.

**2. System Control** the participant is asked to adjust parameters such as zoom level, lighting and movement speed.

**3. Navigation to Information Areas** the participant is asked to move to another area of the virtual environment, containing 2D data and 3D visualizations elements.

**4. Data Selection** the participant is asked to select a pie chart with gaze tracking and pressing on the controller.

**5. Data Manipulation** for the pie chart, the participant is asked to use the tactile rotary elements to expand or contract slices of the pie chart and related data values.

**6. Combined Data Selection/Manipulation I** after navigation to a separate area, the participant is asked to interact with a scaled billboard at a distance and up close: activating buttons, sliders and changing tabular data, with gestures, gaze, or direct in air touch if distance is at arm length.

**7. Combined Data Selection/Manipulation II** the participant is asked to move to another area containing a bar chart, where they can then employ gaze, buttons, in air direct touch, or rotary controls to manipulate the data in the chart.

All participants were directly observed whilst performing the tasks, to obtain general information about the usability of the interface. After completing the tasks, they were asked to complete a short questionnaire of closed questions (using likert scale responses) relating to both the general operation of the interface and also the specific elements of navigation and data selection/manipulation that were the focus of the study. As this was a pilot study, two additional open questions inviting more general observation from each participant were also included to better determine if any other elements of the interface (or task scenario) had been overlooked.

## 6 RESULTS

After performing the guided tasks, a total of 13 participants (2 female, 11 male) completed a short questionnaire evaluating the initial interface. Task scenarios took approximately 15 minutes for all participants to complete. The questionnaire combined short likert response questions relating to the tasks performed with two general questions about the interface that allowed for open response. All participants were undergraduate game design students, with an age range of 19 to 42 (average age 25) most participants also identified themselves as being right handed (10 right, 2 left). It is noted that as a small sample group was used to test the initial interface prototype, no statistical analysis was performed on the results of the evaluation questionnaire (more extensive testing seeking statistical significance is planned for a future implementation of the work discussed in this paper), The responses to some of the questions are presented below and qualitatively analyzed in the discussion .

Participants were initially asked some overview questions relating to the tasks they had just performed, to get a general indication of the validity of the experiment in itself (Figure 2):

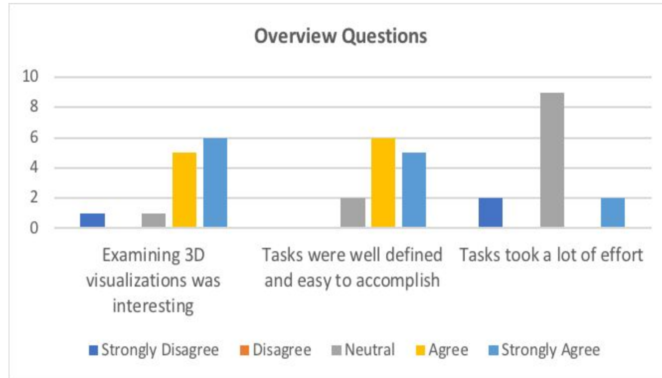


Figure 2 Results for Overview Questions. *Participants were asked about their interest in 3D visualisation and their general opinion on the tasks performed during the experiment. Results are shown by question, with each set of data showing likert responses by number of participants.*

These questions aimed to get a general indication of how the domain (3D visualisation) and the experiment (performing guided tasks) were evaluated by the participants, showing that there was some level of interest (Agree=5, Strongly Agree=6) in 3D visualisation amongst the participants. Participants also showed some level of acceptance of the tasks in the experiment (Agree=6, Strongly Agree=5), but were less sure of the amount of effort those tasks took (Neutral=9). Though this initial result has some merit, later testing will employ the NASA-TLX survey to better evaluate the effort levels required when using this interface.

Participants were then asked to evaluate the general functional level of the prototype for spatial interaction (Figure 3):

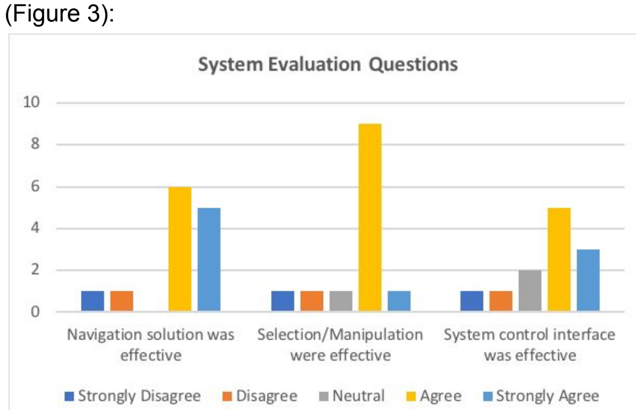


Figure 3 Results for System Evaluation Questions. *Participants were asked to evaluate the navigation, selection/manipulation of data and the interface for system control .*

Results show that most participants considered navigation within the prototype to be effective (Agree=6, Strongly

Agree=5), and that selection and manipulation of elements during the tasks was also carried out in an effective manner (Agree=9). A broad level of acceptance of the system control interface was also indicated, though the presence of less positive responses (Neutral=2, Disagree=1, Strongly Disagree=1) indicates that more investigation of this aspect of the interface is required.

Participants were then asked to evaluate the novel interaction elements employed in the interface (Figure 4):

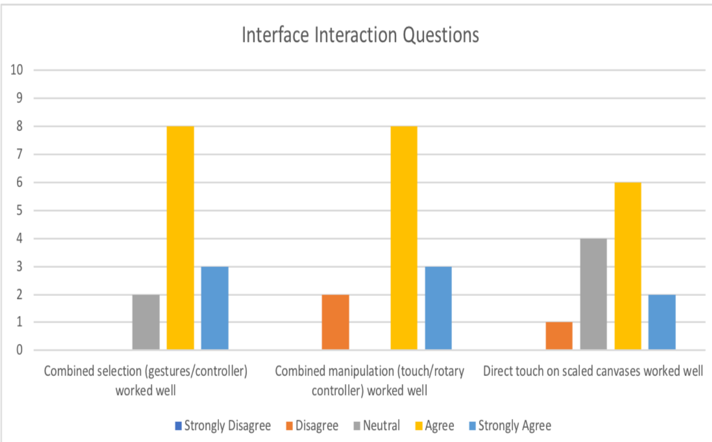


Figure 4 Results for Interface Interaction Questions. *Participants were asked questions about specific interaction elements of the interface- combined selection, combined manipulation and direct touch.*

Results show that combining tactile controller and gestural elements worked well for data selection (Agree=8, Strongly Agree=3), and also for data manipulation (Agree=8, Strongly Agree= 3), though it should be noted that some participants (Disagree=2) found manipulation to be more challenging. The use of direct touch interaction on scaled canvases was less well received (Agree=6, Neutral=4) and the wider spread of results (Strongly Agree=2, Disagree=1) suggests that this technique requires further consideration.

Participants were also asked two general questions about the interface:

1. What did you think was good about this interface?
2. What did you think could be improved in this interface?

The aim of these questions was to try and capture any additional observations or comments that may not have manifested within the closed task evaluation questions (or the general overview questions).

## 7 DISCUSSION

After the initial expert interviews, 13 participants took part in an evaluation of the interface, and filled the provided survey. Exposure to VR varied from owners of commercial VR headsets to first time experience. As no in-depth statistical analysis is carried out at this stage, findings are reported from comments and the results above, but do not attempt to be definite answers .

Of all the participants, one had to stop the evaluation before completing all tasks as he was feeling uncomfortable; cyber sickness is not one of the parameters tested for, as longer periods of immersion would be required, but during use outside the formal evaluation, longer exposure resulted in no adverse effects. One user pushed the navigation solution, doing 360 "loop-the-loops" with no adverse after effects, this was not the purpose of the solution, but produced hilarity in the observers!

The initial expert feedback was invaluable, with comments ranging from interest in the ambidextrous solution, in the multiple ways of pointing at data, and the navigation solution, with a suggestion as to whether bringing the data panels to the user would be a valid alternative or addition to the existing solution of navigating to them with scaling and partial billboarding, pushing the shift from allocentric to egocentric space even further.

A suggestion to add a new interaction of push and twist on the rotary control to achieve "fast continuous change" of a value was suggested as fast spinning of the rotary to increment numerical values was fatiguing.

Both the expert observations and after analysis of the formal evaluation, most users seem to find the 3D mouse a very compelling solution for navigation in VR.

The hand tracking and representation of controllers were amongst the most commented upon, and perceived as making interaction with the hardware controllers "easier", which could be seen as indication that hand presence in the vicinity of interactables is recommended. Data selection and manipulation were listed as "most useful or valuable", alongside the partial bill boarding technique.

In questions as to what was good about the interface similar trends can be observed, albeit the small sample size, with users finding the tactile hardware controllers better than a purely digital interface: "easy to use", "easy to understand" and "helpful" were some of the adjectives used.

Tentative analysis of the results would appear to indicate that 2D panels with UI elements and data visualizations embedded in a 3D environment or in peripersonal space are legible and that elements within them can be selected and interacted with at a distance or within arms length. The scaling and billboarding technique as a bridge between the near and far domain to make content accessible at varying distances provided mixed results, and will need more work to assess whether the scaling technique can be refined.

The use of buttons and a single slider for system control, and of a single rotary button for contextualized selection and manipulation of different values, successfully helped in decluttering the head down interaction space in the near domain for a control interface.

Gaze pointing and button selection as implemented in this instance, with active 6DOF navigation, are seen as valid methods for selecting items on a 2D panel in both the near and far domain, and from different angles, for heads up interaction with data elements in a 3D space.

Combining the interaction techniques used in the application has great potential, users were observed pointing at a panel with one hand and selecting with the hardware button, or selecting zoom with direct touch on the control panel, then doing fine adjustments with the rotary control. These combined techniques would need to be designed specifically as opposed to being an emergent phenomenon, and should be thoroughly evaluated for performance and redundancy. They were nonetheless testament to the robustness of the model.

In the list of improvements, more than one participant asked for an automatic realignment of the view with the floor, this is one of the priorities for further work. Improvements of ratio of camera rotation speed in relation to movement speed was another suggestion, and more feedback from the system when the controllers were being used. More sounds, color, and a specific domain for the data were also suggested.

As an early evaluation, with a small sample of participants, of an interface design, within a domain with few examples of good practice or design guidelines, the qualitative results are considered tentatively positive. A larger more varied sample base and statistical analysis of the results applied to real world analytics tasks are essential, but the enthusiasm of some of the participants was rewarding and a good motivation to further explore the suggested solution, with a real data set, improved setup, and a more thorough implementation of the application and interaction techniques, possibly leading to a more in-depth evaluation seeking statistical significance.

## 8 CONCLUSION AND FUTURE WORK

In this paper some motivational factors were explored for the design and implementation of an interface, to navigate and interact with immersive hybrid 2D/3D visualizations in a virtual environment rendered on a HWD, in the near, far, and control domains. An introduction to related work was followed by details of implementation. A description of the setup, experimental design and discussion of the results of a qualitative evaluation were also presented. The application is perceived by the authors as a promising design for both head-up and head-down interaction in immersive analytics, within a HWD based seated experience. Future work will focus on tightening the interface based on feedback, a more thorough quantitative evaluation, and the expansion of the application to include a larger data set, within a specific 3D environment context.

New hardware with larger resolution, clarity and field of view, with embedded sensors for improved hand and eye tracking is available and worth testing on. The new application to test the interface on is a simulation of autonomous steering agents, navigating procedural geometries, to test selection of moving targets, and data visualization interaction, where the data is being generated by the workings of the simulation itself. The visualizations will be used to gain insight and understanding of the current state of the simulation and of agents behavior, to perform time based comparisons with historical data for location and trajectories, within a collaborative networked application.

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