More Than Blips on the Radar: Exploring Immersive Visualization for Maritime Decision Making

Juliano Franz*
Faculty of Computer Science
Dalhousie University

Joseph Malloch†
Faculty of Computer Science
Dalhousie University

Derek Reilly‡
Faculty of Computer Science
Dalhousie University

Luciana Nedel§
Institute of Informatics
Federal University of Rio Grande do Sul

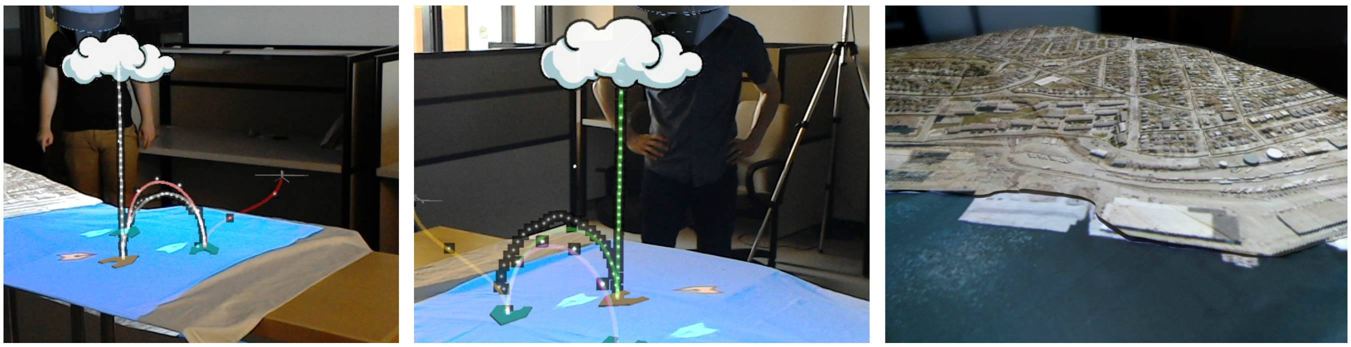

Figure 1: Images on the left and center depict two users exploring communication flow between a group of vessels, drones and cloud data. Each user sees the data categorized by his role, however some elements are constant providing virtual spatial cues for face-to-face collaboration. The image on the right shows a detail of our static tangible tabletop display—the land contour is constructed from CNC-milled wood; aerial photographs or other imagery is added using projection mapping.

Abstract

Decision-making in maritime environments often requires large amounts of data from numerous different sources including local ship-mounted sensors, collaborating vessels in the region and ground stations. On-board data specialists use computer-aided methods to interpret these data and to provide pertinent information for decision makers. Immersive Analytics can help specialists to explore the data more efficiently, however current interaction techniques limit both exploration and adoption. This work discusses current research goals on interaction methodologies for mixed reality immersive visualization for collaborative work. We have created a simple prototype that allows users to collaborate in an immersive environment using multiple HoloLens and a projection mapped tabletop display. In its current form, users can join the augmented reality session (with position and orientation tracking) and visually explore the data.

Keywords: Collaboration, Mixed-Reality, Immersive Analytics, Visual Analytics

Index Terms: H.5.1 [Information Interfaces And Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces And Presentation]: Multimedia Information Systems—User Interfaces

1 Introduction

We live in an era in which most of our decision-making process relies on computer information. From small to big we rely on data from different sources either with some small amount of preprocessing or in a more digested form. As we start having computer solutions that support storage of more and more data we reach an apex where we store more than we can process. Within this configuration, we reach a moment in which the exploration of large datasets can benefit from visual methods [10].

Decision making in the maritime scenario is highly dependent on internal and external data sources. Internal sources are related to an individual vessel's sensors such as radar, sonar, and cameras, whereas external data includes data from ground stations, the cloud, the internal data of another vessel that is part of a coalition of ships, and even social media.

Data specialists and decision makers make use of these complex datasets to plan mission parameters, maneuvers, and encounters. Typically, this data is bound to specific geographic regions and thus can be visualized as overlays on 2D maps on large displays, enabling side-by-side collaboration and discussion.

Augmented reality (AR) displays allow users to overlay information in the real world [13]. Using AR, extra data can be displayed in relation to an existing 2D visualization presented on a wall or tabletop display. AR also facilitates face-to-face collaboration since it does not block the user's view of the physical world in the way that immersive VR does.

Immersive Analytics, as defined by Chandler et al.[5], is the use of immersive technologies and techniques to "support analytical reasoning and decision making" by immersing the user in a dataset. We are exploring how combining 3D visualizations in AR with 2D visualizations on shared displays might create an immersive visual analytics environment that promotes divergent perspectives and face to face collaboration. True immersive data visualization requires interaction techniques that allow direct, "natural" manipulation and selection of data elements; our work considers the combination of in-air gestural interaction with 3D visual elements and touch-based interaction with 2D elements.

While we take our inspiration from maritime scenarios such as coast guard, search and rescue, and naval operations, we feel the

*e-mail: juliano.franz@dal.ca
†e-mail:joseph.malloch@dal.ca
‡e-mail:reilly@cs.dal.ca
§e-mail:nedel@inf.ufrgs.br

findings of our work will apply to a wider range of collaborative data analysis scenarios.

2 Background and Related Work

Collaboration is a key element to enable better exploration of complex data in immersive visual analytics. With the explosion of data generated at work and society at large, it is more important than ever before to examine "off the desktop" visualization tools, including immersive solutions such as large displays, virtual reality, augmented reality, and the combination of multiple techniques [17, 16], such as the use of a projected display combined with augmented reality.

Mixed reality allows users to collaborate seamlessly in an immersive environment that does not separate them from the physical world [3]. It also enables users to participate in face-to-face collaborations benefiting from natural nonverbal visual cues not present in VR and side-by-side projection based approaches [4, 12]. These nonverbal cues can be beneficial for immersive analytics methodologies.

Studierstube [18] was an early work that explored the use of AR for collaboration in an immersive environment. With it, users can seamlessly explore all three-dimensions of the data. They showed that AR provides new levels of interaction (such as natural control of viewpoints) that are easy to learn without removing natural communication channels between users. Benko [2] follows a similar path with VITA, a system that allows archaeologists to explore excavation sites' representations and data back in the lab in a multimodal immersive environment.

The use of augmented reality for immersive visualization does not come without challenges. Olshannikova et al. [14] review the use of VR and AR for big data visualization and list some challenges relevant to our research interests: application support for interaction with and filtering of data elements and subsets; interaction using intuitive gestures; and methods to correctly display virtual objects aligned with their references in the real world.

One of the most advanced commercial AR devices nowadays is the Microsoft HoloLens[1]. A major technical challenge when building interactive prototypes with it currently is that the API does not allow the definition of new gestures. To overcome this, Davies [6] introduced the idea of a toolkit that enables hands and gesture recognition for the HoloLens using external Kinect devices. Yim follows a similar approach [20], focusing on interaction in a collaborative immersive simulation of floods in specific geographical areas also using external Kinects. He and Yang [8] also explore interaction methods for AR (in their case video based) but only for hands. Their solution uses a leap motion attached to the user's HMD. Aside from object manipulation and selection, they also propose an AR menu displayed at the user's hand when she performs the menu gesture.

Similar to immersive VR, AR also lacks a natural force feedback solution. Technologies such as stationary feedback devices such as the Phantom Omni or robotic arms that track the user's hands are not suitable for immersive exploration of data in VR due to the user's freedom of movement. In AR they can also break immersion as the user can see their physical surroundings. Ultrasonic approaches such as the ones proposed by Kovacs et al. [11], in which a system tracks users' hands and emits waves to precise locations are still impractical and current systems such as the ones developed by Ultrahaptics [2] can only produce a small amount of force. Johannes Hummel proposes a different approach for haptic feedback in which the user wears a glove-like device thus not limiting him to a specific location in space [9]. His device provides electrotactile feedback by applying different patterns of electrical current to the user's fingertips.

[1]https://www.microsoft.com/hololens

[2]https://www.ultrahaptics.com/

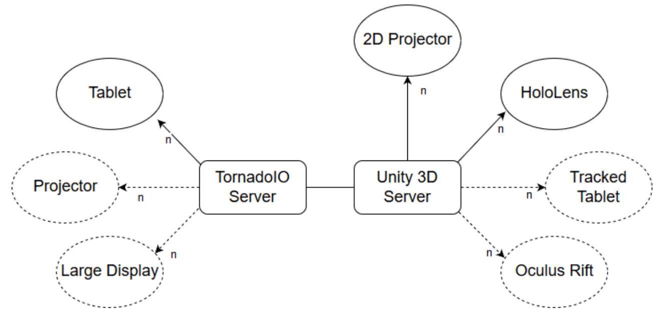

Figure 2: An overview of our collaborative prototype. An Unity3D server serves data for multiple HoloLens clients and also projects information on a tabletop. External clients can receive data from the collaborative session through tablets connected to a server. Elements in the diagram that are with dashed outlines are planned implementations.

3 System Design

We propose a mixed reality system that enables face-to-face collaboration with multiple users in multiple roles. The concept combines a standard 2D map projection visualization in a tangible tabletop and multiple augmented reality head-mounted displays (HMDs). The prototype also allows HMD wearers to work on 3D data visualizations, and send updates to a collaborator's tablet, or to a shared wall display. Figure 2 shows an overview of the current implementation. Elements with dashed lines are planned implementations.

One use case scenario we are considering consists of a coalition of ships that are tasked to collectively search and intercept smugglers in a region-of-interest (ROI). Although the current location of the smugglers is unknown, the vessels have knowledge of possible smuggling routes. By sharing information either from onboard sensors, ground stations or from some cloud computing source, the vessels can coordinate maneuvers to find and apprehend the smugglers.

3.1 Projected table

The projection shows a map or satellite view of the nearby vessels or ROI working as a 'reality' visual cue for the HMDs users. Being a tangible display we also physically render nearby terrain (depicted in Figure 1), but we could also render the ocean floor underneath the vessels as another option. Our implementation makes use of a fixed wood model representing a specific shore line, however, once tangible displays become mature enough it could be used to display nearby terrain in real time.

This physical display also provides an entry point to the visualization, although limited, for users that are not using augmented reality. The users can make sense of high-level information such as proximity of assets and other vessels nearby or underwater terrain depth for maneuvering purposes if using the tangible display as an underwater depth representation.

3.2 AR environment

Data specialists augment their visual perception of the projected table using AR HMDs (Microsoft Hololens) to add another dimension to the represented data. The virtual environment is bound to the physical one, wherein data related to vessel A is rendered on top of the projected vessel A, creating a seamless transition between 2D and 3D. This strong bond between 2D and 3D visual elements is intended to support coordination between HMD and non-HMD wearing collaborators, and between HMD wearing collaborators seeing different 3D content, as described next.

The virtual world supports users with different roles collaborating face-to-face. Each role has a unique visualization based on specific data (see the example below), but we maintain a strict mapping between the spatial position of visual elements and their data sources, such that collaborators viewing different visualizations can still point to regions in space that will pertain to the same underlying data.

In Figure 1(left and center) we show an example where two users are visualizing data transmissions among three vessels in a coalition. One of them is interested in data provenance i.e. the origin of a specific data flow, while the other is interested in data flow types. The first collaborator visualizes a single path in red, indicating the path of a selected stream from the drone to the ship. The second collaborator sees the flows colour-coded according to their type. The location of the data flows are identical for these collaborators, allowing them to point to specific flows during a discussion.

The AR view also displays information relative to each stream such as link speed and noise in the channel in the form of dots moving along the path line. The AR 3D environment also enables rendering information that is not at the same level as the vessels such as drones flying above or underwater assets.

3.3 Information Sharing

It is important for people exploring the data to be able to share this information with others (extract task). We currently allow for data specialists to directly send information from the visualized data or photographs of their current view to tablets connected to a Web server. The data is captured on the HoloLens and uploaded to the server where it is available for decisions makers. Due to current interaction limitations, the amount and quality of the extracted data is not yet very relevant.

3.4 Temporal Summaries on Approach

In a live data visualization, the context and the current situation changes constantly. If someone is not following the data, she does not have an up to date knowledge of it. We propose a solution that briefs newcomers as they arrive at the collaborative session either by using augmented reality devices or tracked tablets.

In our maritime collaborative scenario, this problem could be exemplified in the case where data specialists are working and other people, such as other specialists or decision makers, come to the room for information. To avoid the need for specialists to stop their current task and brief the new people of the current context, we propose the idea of *temporal summaries on approach*.

Temporal summaries on approach work as follows: the immersive environment keeps track of the key elements of the dataset and annotations made by current users. The system should also keep the current knowledge state of every party interested in the visualization, which could either be zero – as in the case where she never interacted with the data – to some level of knowledge. When someone is approaching the collaboration area, the system identifies the differences between the current state of the data and of this person. As she approaches, pertinent information is rendered over time in the HMD display, similar as a briefing.

4 Challenges with AR interaction

Interacting with augmented reality objects can be difficult or seem unnatural. Body tracking technologies might offer a more “embodied” experience during immersive visualization, but these technologies have limitations. Devices such as the Microsoft Kinect and other video-based solutions are suitable when the user stays within a tracking region, but less so in mobile contexts. Additionally, they suffer from occlusion problems when the environment is cluttered and/or there are multiple people working collaboratively in a space. A possible solution is to use devices that are attached to each user, such as a Leap Motion or a Myo Band, but this limits interaction to hand tracking.

4.1 3D Cross to Select

Selecting virtual objects that are out of our arms range is a complicated task in AR. In our prototype system (see Figure 1), users can select individual data flows and expand a detailed view by gazing at the desired flow and using a physical clicker. As the distance to the target increases, the difficulty in selecting it also increases due to perspective and the required angular resolution. Solutions for this problem, such as creating lines that bend towards the target [7], have been explored in previous work but we feel that some improvements are needed for immersive environments that use HMDs.

We propose extensions to the *goal-crossing* technique to 3D environments. Accot and Zhai demonstrated that, for certain classes of selection, crossing a line over items is more efficient and precise than pointing and clicking [1]. We are currently exploring this concept in VR/AR environments, because we believe that it could lead to more precise and natural interactions when compared to pointing techniques for certain 3D visual elements. Although ray-casting works for selecting large elements in the scene, such as a cube, it lacks precision with thin profile objects, such as our flow lines. Crossing also enables users to select multiple objects in a single action as opposed to multiple individual click interactions.

4.2 Low-Fidelity Touch Feedback

Typically, when someone tries AR for the first time, they reach out to touch virtual elements floating in the real world. One of the reasons for that is because force feedback provides powerful spatial cues when we are interacting with our hands in virtual environments. However, very little is done to support it in immersive collaborative environments. What we currently experience in such environments is visual and audio feedback for object selection and interaction.

With proper hand tracking methods, it is possible to detect when the user's hand is near-touching or touching a virtual object in AR. We propose a low fidelity force feedback approach based on the Grasp-Shell [15] algorithm. The algorithm defines three interaction zones for virtual objects in VR based on the finger penetration of a convex hull around the models: Kinematic 1 (0% to 50% penetration), Dynamic (50% to 120%) and Kinematic 2 (more than 120%).

We are exploring the use of a reel loaded line attached to a user's wrist and shoulder. A small spring coil is inserted between the end of the line and wrist to provide different levels of feedback. The reel also creates a pre-load on the string to ensure that it is always stretched. When the user reaches for a virtual object and touches the outer part of the shell (Kinematic 1) the reel locks the line inducing feedback for the user.

If the user wants to push the object away, he can do so by forcing his hand forward entering the dynamic zone to apply regular physics interactions to the object. Because the line is locked in place, the pushing action is enabled by the spring in the middle of the line. As the spring expands, it creates an opposing force according to Hooke's law, which mimics the return force applied by the object into the user's hand.

The user can still grasp the object for manipulation by using his thumb, as described by the Grasp-Shell algorithm. When he does so, he enters the Kinematic 2 zone, which enables free-form manipulation. In this zone, the reel removes the lock and allows the line to move freely.

While we acknowledge that this technique introduces another piece of worn hardware into the environment, it will allow us to examine how such feedback supports users when selecting and manipulating 3D elements in a hybrid 2D+3D environment, particularly since touch feedback is provided on the 2D display. As part of our research, we will compare our proposed technique to a more traditional piezo-based tactile feedback approach to assess qualitative differences and differences in range of expressiveness when coupled with 3D visualizations. It will also be interesting to see how such feedback is useful as a tool for discussing data with collaborators. For example, "third stream from the edge" may be easier for all collaborators to understand if some feedback is provided as they pass through the outer two streams.

4.3 Natural Visualization Gestures

Ben Schneiderman defined seven basic tasks [19] that we tend to use when we are visually exploring and making sense of data: Overview, Zoom, Filter, Details-on-demand, Relate, History, and Extract. Although these tasks summarize most of the steps taken in immersive visual analytics, the existing tools do not yet provide a seamless, natural way to perform such actions on an AR visualization.

We believe that we could learn from everyday gestures that we make when understanding visual information in the real world. It is not rare to observe natural gestures such as squinting to adjust focus; using our hands to shield the eyes from unwanted details or light sources; or moving our heads to disambiguate depth or adjust the apparent level of detail.

Such gestures, and many others, represent how we naturally interact with visual data. However, their use in immersive environments has not been deeply explored. We believe that a proper implementation of such gestures could reduce the separation between reality and immersive environments thus increasing productivity and technology acceptance.

As an example application scenario, we can imagine a user in an immersive VR session exploring data from multiple sources. He could use his hands to shield his eyes to filter out unwanted sources (think of each data source as a bright virtual projector) in the same manner he does with unwanted light sources in real life. If he need more details regarding a specific region of the dataset, he could lean towards that region to review more details. Zooming could be achieved by actively moving closer to the data representation itself and overview by stepping back.

5 Conclusion

In this paper, we present some of our early exploration and research on the use of augmented reality for supporting collaborative immersive analytics of complex data. Our current scenario involves a coalition of vessels working together to search and intercept smugglers in a maritime decision making system. We are actively prototyping a system that allows data specialists to explore heterogeneous data in a collaborative environment using a combination of AR devices and projection mapping. The combination raises a number of important research questions, including how to combine 2D and immersive 3D visualizations, how to support simultaneous heterogeneous but complementary visualizations, applying physical spatial metaphors for interaction, as well as the role of haptics.

As shown in previous studies, AR has several advantages over VR for supporting face-to-face collaboration. However, it lacks proper interaction techniques for data exploration and selection. We believe that the proposed techniques such as low-fidelity haptic feedback, natural gestures, and 3D cross to select can provoke discussion within the research community and help data specialists to adopt immersive AR environments by reducing the separation between virtual and physical through better interaction techniques.

References

[1] J. Accot and S. Zhai. More than dotting the i's — foundations for crossing-based interfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems Changing our world, changing ourselves - CHI '02*, page 73, 2002.

[2] H. Benko, E. W. Ishak, and S. Feiner. Collaborative mixed reality visualization of an archaeological excavation. In *ISMAR 2004: Proceedings of the Third IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 132–140, 2004.

[3] M. Billinghurst and H. Kato. Collaborative Mixed Reality. *Proceedings of the First International Symposium on Mixed Reality*, pages 261–284, 1999.

[4] M. Billinghurst and H. Kato. Collaborative augmented reality. *Communications of the ACM*, 45(7):64–70, 2002.

[5] T. Chandler, M. Cordeil, T. Czauderna, T. Dwyer, J. Glowacki, C. Goncu, M. Klapperstueck, K. Klein, K. Marriott, F. Schreiber, and E. Wilson. Immersive Analytics. *2015 Big Data Visual Analytics, BDVA 2015*, 2015.

[6] C. Davies, J. White, A. McAllister, A. Saroka, O. Addam, F. Hendijani Fard, and F. Maurer. A toolkit for building collaborative immersive multi-surface applications. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces*, ISS '16, pages 485–488, New York, NY, USA, 2016. ACM.

[7] G. D. Haan, M. Koutek, and F. H. Post. IntenSelect: Using Dynamic Object Rating for Assisting 3D Object Selection. *In Virtual Environments 2005*, pages 201–209, 2005.

[8] Z. He and X. Yang. Hand-based interaction for object manipulation with augmented reality glasses. *Proceedings of the 13th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and its Applications in Industry*, pages 227–230, 2014.

[9] J. Hummel, J. Dodiya, G. A. Center, L. Eckardt, R. Wolff, A. Gerndt, and T. W. Kuhlen. A lightweight electrotactile feedback device for grasp improvement in immersive virtual environments. In *2016 IEEE Virtual Reality (VR)*, pages 39–48. IEEE, mar 2016.

[10] D. A. Keim and I. C. Society. Information Visualization and Visual Data Mining. *IEEE Transactions on Visualization and Computer Graphics*, 8(1):1–8, 2002.

[11] P. T. Kovács, T. Balogh, Z. Nagy, A. Barsi, L. Bordács, and G. Balogh. Tangible Holographic 3D Objects with Virtual Touch. *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces*, pages 319–324, 2015.

[12] S. Lukosch, M. Billinghurst, L. Alem, and K. Kiyokawa. Collaboration in Augmented Reality. *Computer Supported Cooperative Work: CSCW: An International Journal*, 24(6):515–525, 2015.

[13] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino. Augmented reality: a class of displays on the reality-virtuality continuum. In H. Das, editor, *SPIE (Society of Optics and Photonics)*, volume 2351, pages 282–292, dec 1995.

[14] E. Olshannikova, A. Ometov, Y. Koucheryavy, and T. Olsson. Visualizing Big Data with augmented and virtual reality: challenges and research agenda. *Journal of Big Data*, 2(1):22, 2015.

[15] T. Piumsomboon, D. Altimira, H. Kim, A. Clark, G. Lee, and M. Billinghurst. Grasp-Shell vs gesture-speech: A comparison of direct and indirect natural interaction techniques in augmented reality. In *ISMAR 2014 - IEEE International Symposium on Mixed and Augmented Reality - Science and Technology 2014, Proceedings*, pages 73–82, 2014.

[16] K. Reda, A. Febretti, A. Knoll, J. Aurisano, J. Leigh, A. Johnson, M. E. Papka, and M. Hereld. Visualizing large, heterogeneous data in hybrid-reality environments. *IEEE Computer Graphics and Applications*, 33(4):38–48, 2013.

[17] J. C. Roberts, P. D. Ritsos, S. K. Badam, D. Brodbeck, J. Kennedy, and N. Elmqvist. Visualization beyond the desktop-the next big thing. *IEEE Computer Graphics and Applications*, 34(6):26–34, 2014.

[18] D. Schemalsteig, A. Fuhrmann, Z. Szavalari, and M. Gervautz. Studierstube An Environment for Collaboration in Augmented Reality. *In CVE '96 Workshop Proceedings*, pages 37–48, 1996.

[19] B. Shneiderman. The Eyes Have It:A Task by Data Type Taxonomy for Information Visualizations. *Proceedings 1996 IEEE Symposium on Visual Languages*, pages 336–343, 1996.

[20] D. Yim, G. N. Loison, F. H. Fard, E. Chan, A. McAllister, and F. Maurer. Gesture-driven interactions on a virtual hologram in mixed reality. In *Proceedings of the 2016 ACM Companion on Interactive Surfaces and Spaces*, ISS Companion '16, pages 55–61, New York, NY, USA, 2016. ACM.