Immersive Maps for Drone Control: A Case for Improving Multi-UAV Ground Control Station Maps with Extended Reality

BRYSON LAWTON, University of Calgary, Canada
FRANK MAURER, University of Calgary, Canada

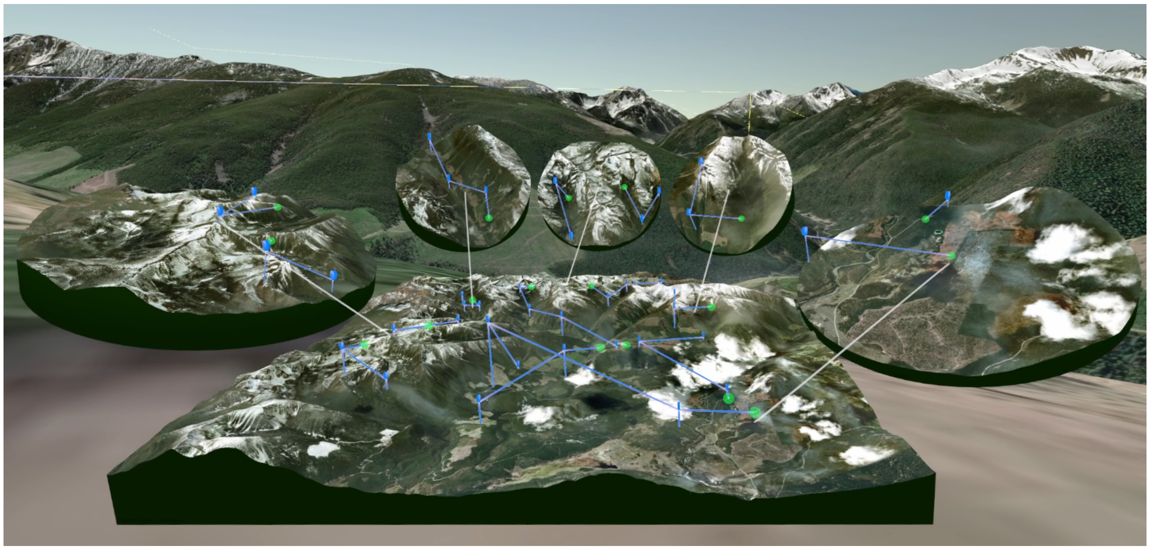

Fig. 1. A collection of 3D maps in extended reality showing the operating environment of multiple unmanned aerial vehicles from different perspectives and zoom levels. The geospatial data of these drones (highlighted in green) and their assigned flight paths (in blue) are visualized on these maps. Note the white lines linking the centers of the smaller maps to their respective locations on the main map.

Ground control stations allow humans to effectively control and monitor drones, the most advanced of which can support the simultaneous command of many tens of independent drones in large-scale, outdoor environments [10]. To best support this, maps are often a central component of their user interfaces in order to best visualize the 3D geospatial data of these drones and how they relate to each other and their operating environment. The capabilities of conventional ground control station software, however, are limited by their traditional 2D screen-based implementation, which negatively impacts the system's scalability, mobility, and how easily users are able to intuitively and accurately understand the three-dimensional nature of these maps and the data visualized on them [15]. This paper presents stereoscopic extended reality technologies as a promising solution to these problems, arguing that by leveraging their strengths not only can one overcome past limitations, but achieve new capabilities simply not possible with prior ground control system methods.

CCS Concepts: • **Human-centered computing → Information visualization**; **Virtual reality**; **Mixed / augmented reality**; **User interface management systems**; **Visual analytics**; • **Computer systems organization → Robotics**.

Additional Key Words and Phrases: Virtual Reality, Augmented Reality, Extended Reality, Mixed Reality, Immersive, Drone, Ground Control Station, GCS, UAV, VR, AR, XR, MR

1 INTRODUCTION

At an increasing rate, unmanned aerial vehicles (UAVs) are being used alongside one another to collectively accomplish tasks more efficiently and effectively than they could achieve individually. To concurrently control and monitor many UAVs, colloquially known as drones, specialized ground control stations (GCSs) are commonly used to allow one or a few people to easily analyze the state of the drones and issue them commands as needed. Conventional GCS software typically employ a 2D screen-based user interface (UI), with two notable commercial examples being UAV Navigation's Visionair [12] and Lockheed Martin's VCSi [10] as seen in Figure 2. Although a relatively effective approach to GCS UIs, the inherent limitations of the screen-based display hardware on which they rely restrict what capabilities are possible with such systems, especially when compared to what is now achievable with modern immersive extended reality (XR) user interfaces. One such aspect of screen-based GCSs which has the potential to be improved by XR technologies are the maps central to their user interfaces, whose current limitations are discussed as follows.

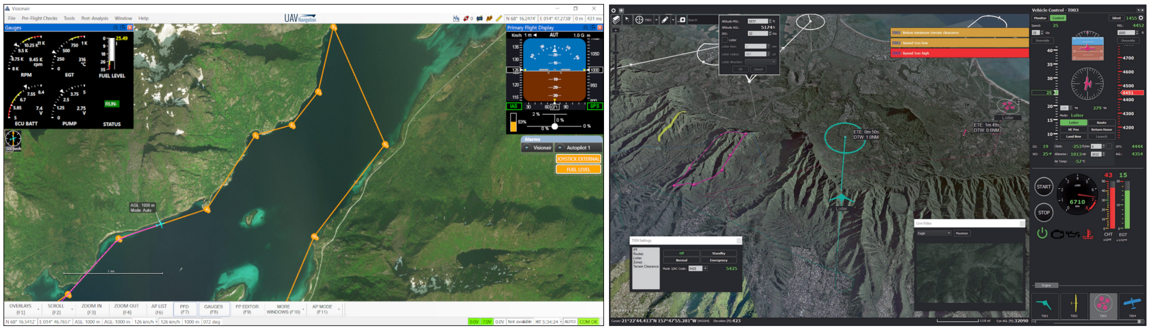

Fig. 2. Screenshots of the Visionair (left) and VCSi (right) multi-drone ground control station user interfaces. Note specifically the 2D (left) and 2.5D (right) central maps which are the dominant aspect of their UIs and the various open windows which occlude these maps. Images are sourced from UAV Navigation [12] and the Lockheed Martin Corporation [10] respectively.

1.1 Traditional GCS Maps & Their Limitations

Most state-of-the-art GCSs typically are centered around one or multiple 2D and 2.5D maps used to visualize the 3D geospatial data of UAVs within their operating environment. Like that of VCSi in Figure 2, 2.5D maps refers to those which utilize a 3D terrain model and 3D coordinate system but are projected onto a 2D image based on the viewer's perspective. For GCSs, this results in a flattened, pseudo-3D view of the operating environment and the drones within it as operators lose a sense of depth important for quickly and intuitively understanding visualizations of natively 3D spatial data. To counteract this loss, one is typically then forced to constantly shift their view of the map to see it from different perspectives. 2D GCS maps are even worse [2, 6], providing a top-down view that often conveys little to no vertical information. If vertical information is visualized though, traditional techniques like contour lines, height color mappings, or context shadows are typically used to help convey important 3D aspects like terrain elevation or building heights in 2D. On the other hand, drone and waypoint heights above ground level are often not even conveyed visually on such maps and instead, as demonstrated in Figure 2, height values are usually just shown as numbers hovering next to their respective elements on the map. Since 2.5D and 3D maps can use these abstract elevation and altitude visualization techniques too though, on top of also more naturally conveying the vertical dimension spatially, one could argue such top-down 2D GCS maps offer a less intuitive representation than higher-dimensional maps for understanding the operating environment's 3D features and the positions of UAVs within it [6, 8, 14].

Placing objective markers in 3D space, like flight path waypoints, is typically done on these 2D and 2.5D maps too. One typically positions such points by clicking on the desired map location with their mouse, however since the mouse cursor does not have a depth component to it, there is a range of 3D positions in space above the map where the user may be wanting to place it. To avoid this issue, some GCSs default to initially placing the marker at the position under the cursor it thinks is best based on context clues and then the user can manually adjust it afterward [10]. This process can become tedious, confusing, and frustrating however, as these kinds of depth-based interactions can be harder, slower, and less intuitive to perform using 2D screens than with immersive XR displays [4].

Another notable issue that arises from traditional screen-based approaches is that the amount of information that can be effectively shown to operators at the same time is directly tied to the display hardware being used and the limited screen real-estate it provides. As seen in Figure 2, screen real-estate limitations can result in the central map being partially occluded at times by other opened UI elements such as various drone information windows. This is not ideal, as such elements could potentially hide important map activity or details behind them. To address this issue, some modern GCSs support multiple displays such that windows can be moved to other screens to avoid occluding others, and with this increased screen real-estate more maps and information windows can then be open and viewed at once [10, 12]. Although certainly an improvement, this still does not remove the issue that system scalability via increasing screen real-estate is directly linked to increasing the display hardware needed, which comes at not only an increased cost but also reduces the mobility of such systems. For instance, some GCSs need to be deployed from laptops or similar mobile devices in the field where bringing along additional screens is often not a viable option.

2 EXTENDED REALITY GCS MAPS & THEIR BENEFITS

Stereoscopic immersive technologies, such as most XR head-mounted displays (HMDs), offer potential solutions to such problems since their inherent strengths can be leveraged to provide improvements to the way 3D geospatial data can be visualized, analyzed, and interacted with using maps simply not possible with conventional display methods. This section not only discusses such potential improvements, but presents images showing examples of how one might implement them within an XR application. These examples have been developed as part of work-in-progress research exploring how many aspects of multi-vehicle GCSs have the potential to be improved through XR HMD technologies, with immersive maps being just one such aspect.

2.1 True 3D Map Visualization, Interaction, & Navigation

The first and most obvious way using stereoscopic XR HMDs can improve upon conventional GCSs is that the stereoscopic nature of such devices displays objects to users in what they perceive to be true 3D. This is an entirely different user experience from the traditional 2D and 2.5D approaches of non-immersive displays as it allows for one to more intuitively understand spatial cues like depth and relative position of objects in space [1, 7, 8]. When applied to GCSs, the 3D maps of the drones' operating environment can now be perceived by users as truly three-dimensional visualizations, two examples of which are shown in Figure 3. This not only has the potential to better support one's natural understanding of the 3D terrain features and building shapes in these maps, but comprehending UAV positions and their movement relative to each other and their environment may also be improved. Understanding the position of floating objective markers may be positively impacted as well for the same reasons and modifying their positions in 3D space may also end up being quicker and easier for users [4]. Gone is the old method of placing waypoints when, as demonstrated in Figure 4, one may instead allow the user to simply reach out in front of them and with their hand quickly place it exactly where they desire in 3D space. XR's ability to support more natural hand interaction via hand-held controllers, hand-tracking, or gestures compared to that of mouse or 2D touch interactions [5] also has potential to support new types of intuitive hands-on interactions with the maps too, such as using one-handed gestures to pan or zoom, or reaching out to touch drones, markers, or environmental features to select them. Furthermore, as an alternative to panning, physical navigation through these maps is now possible via bodily locomotion or virtual teleportation to move around them, and to zoom in one could instead simply just move their head closer to desired features if they wished.

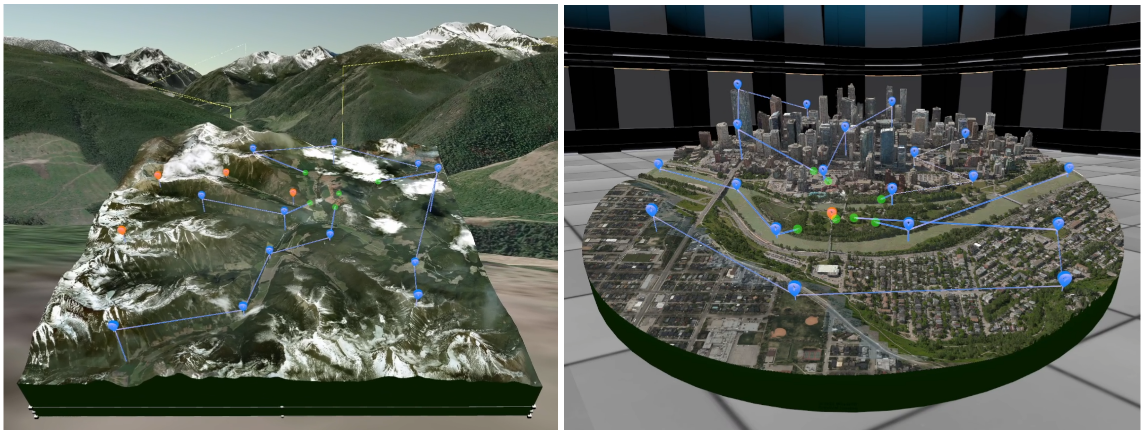

Fig. 3. Two examples of 3D GCS maps in extended reality in which the geospatial and flight path information of many UAVs is being visualized. Left: A GCS map of the Canadian Rocky Mountains within a virtual reality simulation of what it would be like to use an augmented reality GCS map locally from within its operational environment. Right: A GCS map of downtown Calgary, Canada that is being used to control multiple drones from a remote VR workspace.

2.2 Increased Working Space & More Maps

Another advantage XR HMDs offer is that they can provide users with available working space far beyond what is capable with screens [9]. Not only do immersive XR workspaces allow one to place 2D and 3D objects of any size in any direction around the user, but by utilizing depth one can place some workspace elements further away than others, fitting even more into the virtual workspace around them. Although not technically unlimited in size due to graphical hardware constraints restricting how many objects can be rendered at once, this huge amount of usable 3D space around the user allows for workspaces that are no longer limited by typical 2D display hardware constraints and are much more easily able to adapt to large-scale needs. In the case of GCS maps, such available space could be utilized to allow one to scale up 3D maps to the size of entire rooms if desired and allow one to walk around and within them, as is the case in Figure 4. This grants one the ability to immerse oneself in a miniature 3D version of the operating environment and get up-close to map elements they wish to better analyze. This could be especially useful for viewing data or environmental details in a high level of detail without needing to zoom in, since zooming inwards can reduce one's view of the overall map and the geospatial data visualized on it. Avoiding this reduces the chance that other important aspects of the maps are filtered out from view just to place focus on a specific sub-section of the map.

With this extensive amount of usable 3D space, one is also no longer restricted to viewing just a single or a small number of map visualizations at once. Rather, one can now place numerous 3D maps around themselves in different sizes, orientations, and zoom levels to best fit their needs, with Figure 1 demonstrating one such example. It is noteworthy that there are still some limitations to this imposed by occlusion, since a virtual space filled with many 3D objects may at times have some that block the view of others. This, however, can be aided by an assortment of methods, such as positioning workspace objects around the user in an organized manner to minimize occlusion [13], allowing for rapid movement around the workspace to view objects from non-occluded angles, incorporating methods to quickly switch groups of objects on or off, or integrating smart transparency adjustment of non-focused objects [3]. Having multiple maps simultaneously in view grants users the ability to easily switch focus between different UAVs or sections of the operating environment without needing to remove a map entirely from view. For instance, one could have two 3D maps side-by-side and look between them, or have multiple maps around themselves and simply switch focus by rotating their head or body.

This also provides users with the ability to have smaller sub-maps that are zoomed in to each place focus on a specific desired sub-section of the operating environment in addition to the overarching view of larger-scale maps. For example, these sub-maps could be locked to a desired geographical position and zoomed in for keeping a close eye on specific environmental areas of importance, like areas of spreading forest fires or where distressed individuals may be in emergency response applications. Additionally, they could also be used to track specific important drones, allowing one to see the 3D terrain directly around a UAV change as it moves. These sub-maps grant users the flexibility of seeing many concurrent map views at varying zoom levels, supporting the ability to see both large-scale views of the overall environment as well as smaller-scale views without needing to sacrifice one for the other. For improved understanding, sub-maps could also be visually linked to a larger-scale map as seen in Figure 1, so that one has a better idea of where the sub-maps are zoomed in relative to the overall operating environment and how these areas of interest spatially relate to each other in the real world.

Fig. 4. A large-scale view from within the 3D GCS map of Calgary, Canada from Figure 3. To achieve this viewpoint of the operating environment, the user has scaled the map up to the size of a small room, placed themselves inside of it, and is currently in the process of manually placing a waypoint on the map with their controller.

2.3 Improved GCS Mobility & Map Collaboration

HMD-based GCSs also could supply the added benefit of making scalable multi-UAV GCSs much more mobile than they have been in the past. Regardless of if one needs to support a single map view or many, the only physical hardware needed to do so stays the same: a single XR HMD. Thus, so long as the HMD can wirelessly communicate with the drones and the data source for their operating environment's 3D model, one could move anywhere they want and still be able to deploy the GCS. Therefore, as simulated in Figure 3, both remote and local deployment is possible with such systems, allowing one to be in the field and deploy their virtual 3D maps around them while within their real operating environment. Specifically with augmented reality implementations, not only would this enable one to see how their issuing of commands to drones within line of sight are enacted in reality, but also permit the user to actively move around to different real-world locations as needed instead of being stuck to one place.

Collaboration over maps is another notable aspect that has the potential to be improved for GCS deployments where multiple operators are cooperatively controlling large numbers of UAVs. Instead of needing to crowd around a single screen or separately view their own individual maps and try to best verbally communicate what they are seeing to each other, XR HMDs can be utilized to grant operators the ability to share the same large virtual workspace. Whether they connect to this shared workspace via the same point on Milgram's reality-virtuality continuum [11] or through means of cross-reality, a mixture of local and remote collaborators could virtually gather around shared 3D maps as if, for instance, standing together around a large table. Then through more natural physical communication methods, like the hand and arm gestures supported by most XR headsets, they could more clearly and efficiently discuss the task at hand and how to best divide it amongst themselves.

3 CONCLUSION & FUTURE WORK

Stereoscopic extended reality headsets have much potential to improve how one understands and interacts with the maps of multi-UAV ground control stations. Not only with such immersive technologies may 3D geospatial data be better visualized and interacted with in what is perceived to be true three-dimensions, but the display real-estate restrictions of 2D screens is also removed. Eliminating this prior limitation of GCSs would open up a wide range of possibilities regarding the number of usable maps possible within one's workspace and how each map can be customized and positioned around the user to best fit their needs. Moreover, this reduction of hardware requirements could improve the mobility of GCSs and better support working with these maps within desired real-world operation environments. Collaboration over one or many GCS maps also may be enhanced through leveraging the benefits of communal virtual workspaces and allow both local and remote operators to more naturally communicate and work together. A prototype XR software is currently in development to explore such potential and ascertain how XR HMDs may be best used to advance conventional GCSs and improve upon their current issues and limitations. Once development has been completed, a formal evaluation via a user study is planned in order to determine to what degree XR may indeed be an improvement.

ACKNOWLEDGMENTS

The aforementioned ongoing research is funded by Alberta Innovates and the Natural Sciences and Engineering Research Council of Canada (NSERC), who I thank for their support.

REFERENCES

[1] Sahand Azarby. 2021. *Using an Immersive Virtual Reality Interactive Environment (IVRIE) to Improve the Understanding of Spatial Factors in Design: Comparing User Spatial Perceptions Between IVRIE and Traditional Digital Design Environments.* Ph. D. Dissertation. https://ezproxy.lib.ucalgary.ca/login?url=https://www.proquest.com/dissertations-theses/using-immersive-virtual-reality-interactive/docview/2637957526/se-2?accountid=9838

[2] Stephen R. Ellis, Michael W. Mcgreevy, and Robert J. Hitchcock. 1987. Perspective Traffic Display Format and Airline Pilot Traffic Avoidance. *Human Factors* 29, 4 (1987), 371–382. https://doi.org/10.1177/001872088702900401 arXiv:https://doi.org/10.1177/001872088702900401

[3] Dylan Fox, Sophie Park, Amol Borcar, Anna Brewer, and Joshua Yang. 2018. *Element Selection of Three-Dimensional Objects in Virtual Reality.* 13–29. https://doi.org/10.1007/978-3-319-91581-4_2

[4] Nicolas Gerig, Johnathan Mayo, Kilian Baur, Frieder Wittmann, Robert Riener, and Peter Wolf. 2018. Missing depth cues in virtual reality limit performance and quality of three dimensional reaching movements. *PLOS ONE* 13, 1 (Jan 2018), e0189275. https://doi.org/10.1371/journal.pone.0189275

[5] Robert J.K. Jacob, Audrey Girouard, Leanne M. Hirshfield, Michael S. Horn, Orit Shaer, Erin Treacy Solovey, and Jamie Zigelbaum. 2008. Reality-Based Interaction: A Framework for Post-WIMP Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Florence, Italy) *(CHI '08)*. Association for Computing Machinery, New York, NY, USA, 201–210. https://doi.org/10.1145/1357054.1357089

[6] Mark St. John, Michael B. Cowen, Harvey S. Smallman, and Heather M. Oonk. 2001. The Use of 2D and 3D Displays for Shape-Understanding versus Relative-Position Tasks. *Human Factors* 43, 1 (2001), 79–98. https://doi.org/10.1518/001872001775992534 arXiv:https://doi.org/10.1518/001872001775992534 PMID: 11482314.

[7] Bireswar Laha, Kriti Sensharma, James D. Schiffbauer, and Doug A. Bowman. 2012. Effects of Immersion on Visual Analysis of Volume Data. *IEEE Transactions on Visualization and Computer Graphics* 18, 4 (2012), 597–606. https://doi.org/10.1109/TVCG.2012.42

[8] Yemon Lee, Stefan Marks, and Andy M. Connor. 2020. An Evaluation of the Effectiveness of Virtual Reality in Air Traffic Control. In *Proceedings of the 2020 4th International Conference on Virtual and Augmented Reality Simulations (ICVARS 2020)*. Association for Computing Machinery, New York, NY, USA, 7–17. https://doi.org/10.1145/3385378.3385380

[9] Lee Lisle, Xiaoyu Chen, J.K. Edward Gitre, Chris North, and Doug A. Bowman. 2020. Evaluating the Benefits of the Immersive Space to Think. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. Institute of Electrical and Electronics Engineers, New York, NY, USA, 331–337. https://doi.org/10.1109/VRW50115.2020.00073

[10] Lockheed Martin. 2022. VCSi. Retrieved March 19, 2022 from https://www.lockheedmartin.com/en-us/products/cdl-systems/vcsi.html

[11] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. 1994. Augmented reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies* 2351 (01 1994). https://doi.org/10.1117/12.197321

[12] UAV Navigation. 2022. Visionair - GCS Software: UAV Navigation. Retrieved March 19, 2022 from https://www.uavnavigation.com/products/ground-control-station/visionair-gcs-software

[13] Kadek Ananta Satriadi, Barrett Ens, Maxime Cordeil, Tobias Czauderna, and Bernhard Jenny. 2020. Maps Around Me: 3D Multiview Layouts in Immersive Spaces. *Proc. ACM Hum.-Comput. Interact.* 4, ISS, Article 201 (nov 2020), 20 pages. https://doi.org/10.1145/3427329

[14] David Schobesberger and Tom Patterson. 2007. Evaluating the effectiveness of 2d vs. 3d trailhead maps. In *Mountain Mapping and Visualisation: Proceedings of the 6th ICA Mountain Cartography Workshop*. 201–205.

[15] Harvey Smallman, Mark St John, Heather Oonk, and M. Cowen. 2001. Information Availability in 2D and 3D Displays. *IEEE Computer Graphics and Applications* 21 (09 2001), 51–57. https://doi.org/10.1109/38.946631