Exploring Extended Reality Multi-Robot Ground Control Stations

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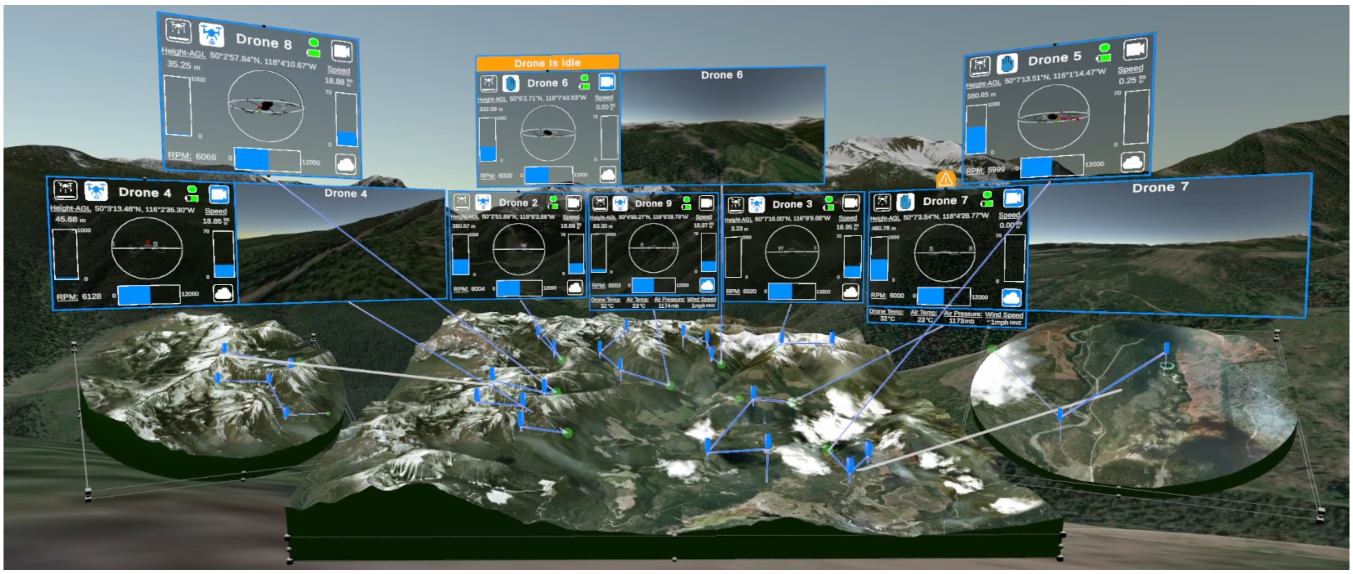

Figure 1: An extended reality ground control station workspace made up of a collection of 3D maps and robot information panels. Visualized on the three maps, one sees different perspectives of the operating environment for multiple aerial drones (highlighted in green) and their assigned flight paths (in blue) from varying zoom levels.

ABSTRACT

This paper presents work-in-progress research exploring the use of extended reality headsets to overcome the intrinsic limitations of conventional, screen-based ground control stations. Specifically, we discuss an extended reality ground control station prototype developed to explore how the strengths of these immersive technologies can be leveraged to improve 3D information visualization, workspace scalability, natural interaction methods, and system mobility for multi-robot ground control stations.

KEYWORDS

Virtual Reality, Augmented Reality, Extended Reality, Mixed Reality, Immersive, Robot, Ground Control Station, GCS, VR, AR, XR, MR

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1 INTRODUCTION

Ground control stations (GCSs) are a commonly used tool that allows humans to control and monitor robotic vehicles, such as aerial or terrestrial drones. State-of-the-art GCSs, such as UAV Navigation's Visionair [5] and Lockheed Martin's VCSi [3], even support the collective control of multiple robots simultaneously by a single human, which can either be done locally on-site from where the robots are operating or from some remote location. The extent of their effectiveness, however, suffers from the constraints of their traditional 2D screen-based user interfaces (UIs). Regardless of the size and number of physical screens used to support such a GCS, the display real estate available is still limited. When this limit is reached, the GCS UI may no longer be able to present all necessary information to operators at once, which in turn constrains how many vehicles can be simultaneously controlled effectively and efficiently by a single person. In addition, by adding more screen hardware one reduces the mobility of such systems which restricts how easily they can be deployed and moved around in the field. Modern GCSs typically also visualize the 3D geospatial data of robots within their operating environment using 3D maps, however 2D displays flatten these maps to pseudo-3D perspectives, removing such information from being perceived and interacted with in its natural dimensions.

Extended reality (XR) head-mounted displays (HMDs) on the other hand suffer no such limitations. The display real estate available in XR is far beyond what is capable with screens [2]. Thus in immersive XR workspaces, not only does one have the display real estate to place any number of virtual objects around themselves in any size and direction, but since XR HMDs display virtual surroundings in what one perceives to be true 3D, one can also visualize and interact with natively 3D information using truly 3D data visualizations. As such, XR HMDs remove the physical constraints imposed by screen-based hardware on how much can be displayed at once to users, instead offering them much more scalable and customizable working space to utilize. To explore how such benefits may be best used to improve upon the UIs of conventional multi-robot GCSs, an in-progress XR GCS user interface prototype has been developed as part of ongoing research, whose current main features are discussed in the following section.

2 EXTENDED REALITY GCS KEY FEATURES

2.1 Information Panels & 3D Maps

For every robotic vehicle being controlled by the GCS, all available data concerning its state such as its speed, position, orientation, battery level, local environmental conditions, camera feed, and notifications can be found in each robot's virtual information panel. Examples of these panels in various states can be seen in Figure 1. Parts of these info panels can be minimized to remove unnecessary workspace clutter and reduce information overload when certain info does not need to be presented to operators. To visualize the 3D geospatial data of robots within their operating environment, virtual 3D maps like those in Figure 1 are used. Presenting 3D geospatial and terrain information in perceived three dimensions, these maps are aimed to more intuitively convey such information when compared to their pseudo-3D counterparts. Using natural gestures, operators can perform hands-on pan and zoom interactions with these maps to create customized views that place focus on important drones or specific parts of the operating environment. Pins on maps can also be placed, selected, moved, and deleted with one's hands to perform actions like selecting specific robots or setting waypoints for a robot's autopilot to follow. Info panels can also be visually linked via lines to their respective robots on these maps for improved spatial context of the information being presented.

2.2 Increased Working Space

By taking advantage of the vast amount of available working space within XR environments, any number of these information panels and 3D maps can be created at once around a user to form a virtual workspace that scales with their needs. Because they are entirely virtual objects, the XR GCS's mobility stays the same regardless of how many are created since the only display hardware needed remains solely the XR HMD itself. This increased space even gives operators the option to scale 3D maps up to the size of entire rooms if desired, in which they then can walk around to take a closer look at its finer details in a sense of scale not possible using 2D screen-based methods. Even if one does not have the real-world space to physically move around, they can still do so in the virtual environment by way of a teleportation functionality that grants one the ability to navigate even vast virtual workspaces without having to take a physical step.

2.3 Main Menu & General Interactions

A collapsible, wrist-mounted main menu moves with the user and allows for compact navigation between all of the XR GCS's features, including the issuing of commands to robots and the spawning of info panels and 3D maps. Once created, panels and maps can all be moved around the environment by grabbing them with one hand or controller, as well as scaled and rotated by grabbing with both hands or controllers. For finer rotation and scaling, their toggleable bounding boxes seen in Figure 1 can also be manipulated. Together, this allows users to fully customize the layout of their workspace to best fit their needs and preferences.

2.4 Deployment & Simulation Environments

The XR GCS UI prototype can run in virtual reality (VR) or augmented reality (AR) using either the HTC VIVE [1] or Hololens 2 [4] respectively and simulate both local and remote control of multiple vehicles using virtually simulated robots. Two large-scale VR test environments simulating real-world use cases have also been developed. The first of these simulates the control of a fleet of aerial drones deployed in Canada's Rocky Mountains to assist in emergency response efforts. The second is a simulation of a future Martian astronaut exploring & mapping the Martian surface using a combination of terrestrial rovers and aerial drones. These simulated robots and environments allow for the evaluation of this novel GCS user interface in different types of deployment situations without needing to physically go to such places, recreate dangerous circumstances, or require access to a large number of the expensive, high-quality robotic vehicles typically used in such circumstances.

3 CONCLUSION & FUTURE WORK

Immersive extended reality user interfaces for ground control stations have much potential to improve upon the current limitations of traditional multi-robot ground control stations which rely on 2D screens. Such immersive technologies could allow GCS operators to better visualize and interact with the 3D geospatial data of robotic vehicles using truly 3D maps. They are also no longer held to the display real estate restrictions of 2D screens, which opens up a wide range of possibilities for how workspaces can be customized and scale with operator needs while maintaining their mobility. The prototype XR GCS user interface discussed is being iterated upon to further explore such potential and determine how XR HMDs may be best used to improve upon the present issues and limitations of screen-based GCSs. Once the refinement of this prototype has been completed, a formal evaluation is planned via a user study to ascertain to what extent this XR approach may indeed offer an improved user experience over conventional GCS UIs.

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