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Tactical and Strategical Analysis in Virtual Geographical Environments

Bettina Schlager* VRVis Forschungs-GmbH
Daniela Stoll† VRVis Forschungs-GmbH
Katharina Krösl‡ VRVis Forschungs-GmbH
Anton Fuhrmann§ VRVis Forschungs-GmbH

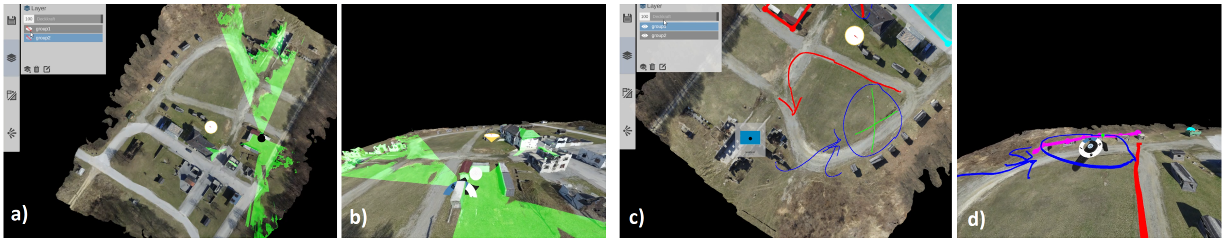

Figure 1: A snapshot of our immersive tactical analysis tool. (a) - (b) show the line-of-sight analysis and (c) - (d) show the annotation functionality for the desktop and VR user respectively.

Abstract

Planning tactical and strategical operations on a terrain is a well structured and complex process. It is usually executed by a group of interdisciplinary experts with different objectives. Traditional equipment for tactical analysis like paper maps or sand tables cannot transfer spatial understanding for visibility analysis and height judgment. Immersive virtual geographical environments offer additional perspectives for rapid decision making and reasoning of spatial structures. We propose a collaborative multi-user virtual reality system for the tactical analysis of terrain data to support mission planning.

Index Terms: Computer Graphics [I.3.7]: Three-Dimensional Graphics and Realism—Virtual Reality

1 Introduction

Virtual geographical environments (VGEs) are well-established in various applications such as flight simulation, space exploration, disaster preparation and urban design. This work presents a multi-user virtual reality (VR) system using geographical terrain data aiming to support tactical analysis for mission planning. Widely used non-digital equipment for tactical analysis of terrain and field mission planning are sand tables and common paper maps. Such tools are used to help mission leaders make rapid decisions about important tactics, logistics and operational maneuvers. Through observations of mission training in a real-world setting and consultations with experts in the field, we found that crucial criteria during decision-making are visibility estimation, like line of sight, geographical distances and height judgment. Previous studies [2] involving paper maps and sand tables showed that participants performed better using elevated maps, in terms of tactical task execution time and accuracy. Boyce et al. [2] argue that flat maps are time-consuming and possess a high mental workload. Users have to mentally reconstruct the terrain to derive insight for the task at hand. Similar to our system, García et al. [3] proposed a collaborative immersive setup for mission planning using geographical space data. Their expert test results showed that the improved 3D perception had a positive impact on slope analysis of simulated space terrain. In the context of disaster preparation, i.e., assessment of geohazards, Havenith et al. [4] evaluated various immersive technologies and reported that VR systems are useful to solve various problems related to geographical scenes that involve the analysis of complex geometries. In general, past research repeatedly showed that immersive virtual environments (VEs) offer improved spatial understanding [1] and thus facilitate better understanding of spatial relationships between scene elements, compared to 2D alternatives.

In this work we leverage the benefits of immersive VGEs for mission planning and present a **collaborative VR system** for exploration and tactical analysis of geographic terrain in real-time. A user can interact with the 3D terrain data in the VE from different perspectives for advanced terrain analysis. Our application allows one VR user and a desktop user to **work collaboratively together on the same terrain data**. The application supports decision-making by offering features for **terrain annotations**, **distance measure** and **visibility analysis** on the desktop and in VR, (see Figure 1) as well as functionality to **export results** in a reusable format. The main contribution of our work is the design of a VR system that offers a base for team collaboration for mission planning. The application supports complex decisions where the spatial understanding of terrain is crucial. The current application design is tailored to the tactical analysis during mission planning for military use cases, but can also be applied to other application areas with similar requirements, such as emergency response training or flood management.

2 Requirement Analysis

Based on our observations of tactical operation test groups in real-world settings, we identified the following requirements for our application: *(1) The design of the application has to integrate different user roles and alternating planning phases.* During mission planning, multiple groups of experts annotate the terrain data to create a tactical plan according to their group's goal. During the presentation phase, the expert groups present their results to the mission commander. The commander integrates the information of the different groups in VR, relying on a presenting officer on the desktop GUI to present the data. *(2) Support for various spatial resolutions of geographical data.* The terrain data sources vary widely in scale, from a few blocks of urban environment reconstructed from drone images, to terrain received from satellite data with an extent of more than 100km^2. *(3) Annotations should be organized in layers.* Through our observations during the planning phase, we learned that different groups of experts work on the same terrain data. They add annotations based on their unique goal and are not concerned with the plans of all the other groups at this point. Later on, the annotated plans of each group are needed in the presentation phase

*e-mail:schlager@vrvis.at
†e-mail:stoll@vrvis.at
‡e-mail:kroesl@vrvis.at
§e-mail:fuhrmann@vrvis.at

to fuse them into an overall mission plan. Therefore, the application needs to support isolated views for experts during planning as well as functionality to switch through each individual plan and combine them in the presentation phase.

3 System Design

Based on the above listed requirements we designed our application as shown in Figure 2: Our rendering engine for terrain simulation targets two output devices, a VR headset (HTC Vive Pro) for the *VR user* and a large monitor or projector for a *desktop* user to interact with the terrain or present the data to multiple experts for discussions. The VR user and the desktop user are able to directly interact with the *terrain* (terrain data and elements in the scene), using *controller input* and *tracking data* or *desktop input* (mouse and keyboard) respectively. The *Data input* of our system consists of textured *terrain data* in a standard 3D file format and a *project meta data* file providing additional project-related information, such as used geographical projection and visual settings. The annotations on the terrain are organized in layers and can be imported from previous planning sessions and exported as *layer data* for presentations or other GIS systems.

4 Interaction Design and Functionality

The desktop interface is equipped with functionality to add or delete annotations, change terrain texture and adapt visibility of annotation layers. It has two different perspectives on the terrain, an orthographic view from the top and a 3D view, showing the current view from the VR user's perspective. The VR user interface consists of two radial menus attached to the touch pad of the controller. One controller provides functions for spatial navigation and the other allows to control the system. The system control menu displays functionalities based on the current mission phase. During the presentation phase, the VR user takes over the role of the mission leader with the objective to comment and analyze elements of the terrain. During the planning phase, the role of the VR user changes to an operational expert, who can add complex annotations.

An advantage of 3D terrain data over flat maps is the suitability for visibility evaluations. Our application offers a function to select a position for the visibility calculation. The surrounding terrain visible from this point is highlighted in color, allowing both users to evaluate line of sight (see Figure 1 (a) and (b)).

4.1 Layer Management

The desktop and VR users are able to freely place points, lines, areas and military map marking symbols according to the NATO standard in the scene. Further, the VR user can draw lines in 3D.

During the presentation phase, the objective of a mission leader is to analyze the tactical strategy of the groups individually or combined, based on the annotations created by the expert groups during the planning phase. Therefore, we decided to organize annotations in exportable layers. This enables expert groups to work independently, but simultaneously (on different hardware) on the same terrain data (and export their plans for the presentation phase), effectively reducing execution time of the planning phase.

4.2 Navigation

Free viewpoints and dynamic navigation allow the decision-maker to adopt the tactics and strategies aligned to the mission goal accordingly. We decided to implement three different navigation methods, depending on the desired perspective or travel distance: *table, first-person and helicopter navigation*. The first one is similar to a virtual sand table [2]. The whole terrain is fitted to the calibrated area of the VR system. The user can then interact with the scene elements similar to a real-world sand table. A virtual pin can be placed anywhere on the terrain and used to switch to first-person mode at the specified location. The first-person mode also features close range navigation via the common "teleportation" metaphor. In the last mode, the helicopter navigation, the VR user can use the touch pad on the navigation controller to move freely around the scene.

5 Preliminary Results and Future Work

We developed our application following a participatory design approach: we worked closely together with expert users to continuously improve the interaction techniques in the VE as well as functionalities for the desktop user. The application is currently used in different departments of the Austrian army and is going to be integrated in the training curriculum for officer candidates. While we did not conduct a formal user study yet, initial results demonstrated a strong interest in the application due to its novelty for the field. The collaborative aspect, immersive viewpoint, 3D interactions with the terrain, as well as the line-of-sight analysis, offer qualitative advantages compared to current alternatives. One limitation of our application however is that the quality and accuracy of quantitative measurements on the terrain heavily depend on the terrain resolution. As an example, a coarse terrain reconstruction from satellite images might lead to an inaccurate line-of-sight analysis. Our application runs locally on one computer assuming the expert group, VR user and desktop user, are in the same room. In future work, we plan a more flexible server-client framework which enables remote collaboration and scene import. Further, we want to conduct a user study and analyze potential improvements to task completion time and accuracy when using our system compared to currently used workflows and tools such as paper maps.

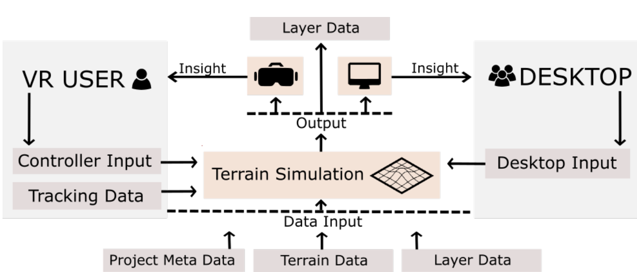

Figure 2: Data and information flow of the proposed application.

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