Cooperative and location-independent terrain assessment for deployment planning using a 3D mixed reality environment

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ABSTRACT

A fast and reliable decision is based on the availability of a precise data basis and expert knowledge. In order to address these aspects for resource planning, we provide an intuitive situation analysis in mixed reality with a seamless transition between conventional location planning and virtual inspection of the operational environment, which in addition to a better understanding of the terrain allows for location-independent cooperation of several users. The basic idea of the presented concept comprises the intuitive application preparation in mixed reality in a realistic 3D environment combined with an efficient 2D situation overview using e.g. a large display, tablet or smartphone. The aim is to enable transparent collaboration between different system environments regardless of the location of the respective users. The aim of the idea is an improved understanding of the terrain and increased situational awareness for fast and demand-oriented location planning. The solution is based on the three building blocks. First, a user-oriented display of high-resolution 3D geodata for a better understanding of the terrain on the basis of data standards, including necessary performance optimizations for use in mixed reality environments. Second, the combination of two-dimensional and three-dimensional display of operational pictures, which allows a choice of means through the synchronization of the information between the different platforms and thus a demand-oriented deployment planning. And third, the support of content-related cooperation of remote users for fast decision making via wired or mobile networks

Keywords: virtual reality, mixed reality, common operational picture, collaboration, GIS

1. INTRODUCTION

Any kind of complex planning requires a wide variety of expertise. In many cases, this expertise is spread over several people. It is therefore important to have the required means to allow multiple people to bring their expertise to the planning process and distribute the information among all participants. Often not all relevant persons can be at the same location, which means, that traditional planning using e.g. a paper map and drawn annotations do not work in many cases. Digital planning tools are often tailored to personal computer usage, which means they are not designed to be used by multiple people at the same time. We base the mixed reality system presented here on a software system that allows both, local collaboration by specifically addressing usability issues of large touchscreen displays suitable for multiple users and remote collaboration by real-time synchronization via a network. Figure 1 shows the range of supported devices with the fourth from the left being a digital table that allows multiple users to collaborate using large touchscreens. The software, based on web-technology is accessible on any device with a browser without the need to install anything. Every client is connected to a backend server, making sure that all users have access to the same information at all times.

While a large display is optimal for collaboration, it requires all participants to be at the same location. The system presented here aims to make this requirement superfluous. By recreating large displays in a virtual environment, we can bring all functionality that is available in the existing software to virtual reality. This has two main advantages. First, by bringing multiple people into this virtual world, we can enable remote collaboration that is just as intuitive as being onsite. Second, by exploiting the implicit advantages of virtual reality (VR) we can even go beyond what is currently possible on screens in the real world and display three-dimensional data using the stereoscopic display capabilities of virtual reality headsets.

The following sections will give an overview of related work, introduce the features of the software we based our system on and then go into details of the implementation of our mixed reality system especially with regard to local and remote collaboration before we end with a conclusion and outlook on future work.

Figure 1: Display of a common operational picture across a wide range of devices. From a mobile phone on the left to a virtual table, along with a VR headset and controllers, on the right.

2. RELATED WORK

The potential of the ease of access of web-based systems in combination with the advantages of three-dimensional visualization have been known for some time. Doyle et al. [1] show a web-based mapping system that is enriched by a (also web-based) virtual reality modeling of urban environments. While this does not yet utilize dedicated virtual reality hardware such as HMDs it shows the potential of the combination of these technologies. Since the real world is three-dimensional the work on GISs (Geographic Information Systems) that support three-dimensional visualization started early as shown in “Virtual GIS: a real-time 3D geographic information system” by Koller et al. [2]. The first available HMDs for virtual reality allowed for first experiments with interactive, geodata-visualization [3] but lacked collaboration and use of three-dimensional geodata. While not usable for deployment planning as it lacks any features beyond exploring data, Google has made an impressive step towards interacting with three-dimensional geodata in virtual reality with “Google Earth VR” [4]. It does, however, rely on Googles data which may or may not be accurate or up-to-date and without a way to use it with custom data it is not suitable for terrain assessment or deployment planning at least not in a military context. Yalong Yang, Bernhard Jenny, Tim Dwyer, Kim Marriott, Haohui Chen, Maxime Cordeil have explored more ways to visualize three-dimensional geodata in virtual reality in “Maps and Globes in Virtual Reality” [5]. Their results provide support for the use of exocentric globes for geographic visualization in mixed-reality. Šašinka et al. [6] have studied both, collaboration and the display of geographic data in virtual reality, however, with a focus on education and have shown the effectiveness of dynamic and interactive 3D visualization. While at the current state of available headsets, virtual reality offers a much wider field of view there are advantages to augmented reality headsets as well as Wang et al. show in “Holo3DGIS: Leveraging Microsoft HoloLens in 3D Geographic Information” [7]

3. THE DIGITAL MAP TABLE

The digital map table (DigLT) is a software system for shared situation visualization and analysis. Any number of users can work independent of each other on the same situation, using personal computers and tablets alongside shared digital tables or large screens. The underlying software is modular and can easily be custom-tailored towards specific needs and extended depending on the requirements. Its uses range from educational use to mission preparation, mission execution, and review. A diverse range of data sources and geodata can be integrated to provide the right information for each use-case. This provides the basis to correctly judge the situation and make the right decisions.

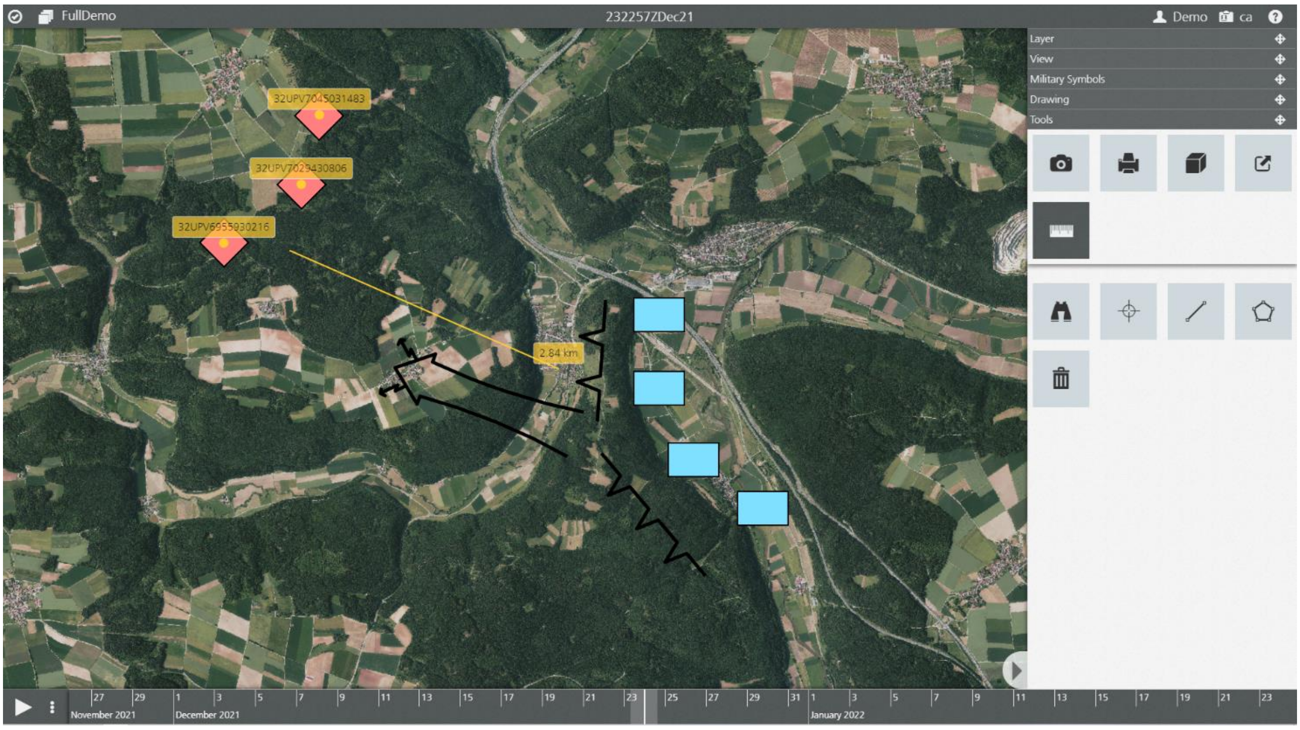

Figure 2: A screenshot of the web-based DigLT software.

The concept of individual layers for visualizing and editing allows users to adjust and filter the displayed information on the map. Layers can be stacked and blended to combine all information into a single coherent view. DigLT provides interfaces for many different internal and external sources of data, thus allowing layers to contain a wide range of 2D and 3D maps and additional information such as annotations, reconnaissance data, live video feeds, blue force tracking etc. Currently supported functionality ranges from drawing and measurement tools, use of APP6 symbology, viewshed visualization, up to a timeline, which allows to freely move through time and experience situational awareness in four dimensions. The DigLT software runs on a wide variety of connected devices. By adhering to standards, all devices can access all available data sources. This includes standards from the Open Geospatial Consortium (OGC) as well as a wide range of NATO standards. The open and modular architecture allows for easy integration of proprietary interfaces as well. All information can be kept in separate layers, which can be updated independently and arbitrarily combined for visualization. A web-based client is used to display all information which allows for great flexibility as many user devices integrate a browser. The DigLT can easily be integrated into any environment. The underlying technology supports any major operating system and the wide variety of interfaces allows for easy connection to existing data sources. Especially the support of OGC standards such as Web Map Service (WMS), Web Feature Service (WFS), Styled Layer Descriptors (SLD) and NATO standards such as STANAG 4609, 4545, 4559 and 4676 guarantee easy interfacing with the DigLT software.

Due to the current state of virtual reality development, one immediate challenge for creating a VR version of the DigLT software is that web-based virtual reality does not yet provide a good enough performance for complex data visualization. At this time, only game engines such as Unity [8] or Unreal [9] are options that allow for high performance when creating complex VR applications. Therefore, it was necessary to create a dedicated client using a game engine, but at the same time avoiding a reimplementation of all the features and functionality that already existed. We opted for a dedicated Unity client that uses a browser element in VR to display the existing software in VR. It is not only possible to see the software in VR but also to interact with it, giving access to all functionality. By adding networking to the dedicated client that allowed multiple users to enter the same virtual environment it was already possible to remotely collaborate with a large, virtual screen running the existing DigLT software.

As mentioned in the introduction, one of the intriguing features of VR is the stereoscopic display which allows for true visualization of three-dimensional data. In the context of deployment planning this is especially interesting with regard to the geographic data. To leverage this advantage, the dedicated VR client needed a dedicated visualization system for geographic data. Since our goal is the display of three-dimensional data as accurately as possible we started out with a three-dimensional globe, with a shape based on the geoid. Given georeferenced data such as aerial images, it is possible to place them at the correct location on the globe. If a digital elevation model is available as well, the exact surface can be respected when displaying the geographical imagery. Displaying geographic data on a 3D globe has the advantage, that no map projection is necessary, allowing for an accurate representation of the real world. To allow for collaboration with this data in a way users are acquainted to, we decide to revisit the table metaphor and create a table in VR that contains the globe. To fit the globe into the table we created a round table and cut off parts of the globe that go beyond the extend of the table (see Figure 3).

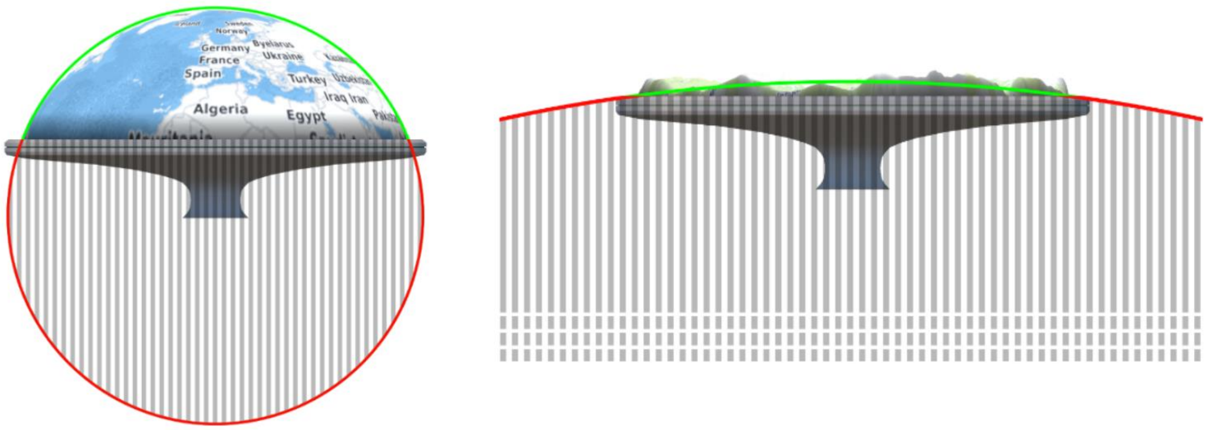

Figure 3: Fitting the globe into the (virtual) table. Depending on the scale, the globe is not recognizable as such (right).

Because everything beyond the extent of the table is not visible to users, the fact that all visualization of geographic data is based on a whole globe is usually not apparent to users unless they zoom out far enough for large parts of the globe to be visible within the boundaries of the table. Another challenge with regard to the display of the geographical data is caused by trying to keep all data within the bounds of the table. Depending on the elevation at a given point on the globe, the map data might not be below the edge of the table (see Figure 4 left in comparison to middle). This would allow the user to effectively look below the mesh, which is not helpful and can be irritating. To mitigate this effect, we artificially pull the map down at the edge of the table (see Figure 4 right). This causes the map to always disappear at the edge of the table as seen in Figure 5. For actual deployment planning it is of course not sufficient to just display map data, additional information such as annotations and military symbols need to be displayed as well.

Figure 4: Illustration of the problem of displaying a 3D surface within the bounds of a table.

To allow for a fluent switch between the existing web-based software and the dedicated VR-client they need to be synchronized. The core of the DigLT software is a server backend which serves geodata, layers, configurations and provides all functionality. Both the web-based client and the virtual reality client get all data from the same back end. This ensures that all information is shared and people get the same information no matter what client is used.

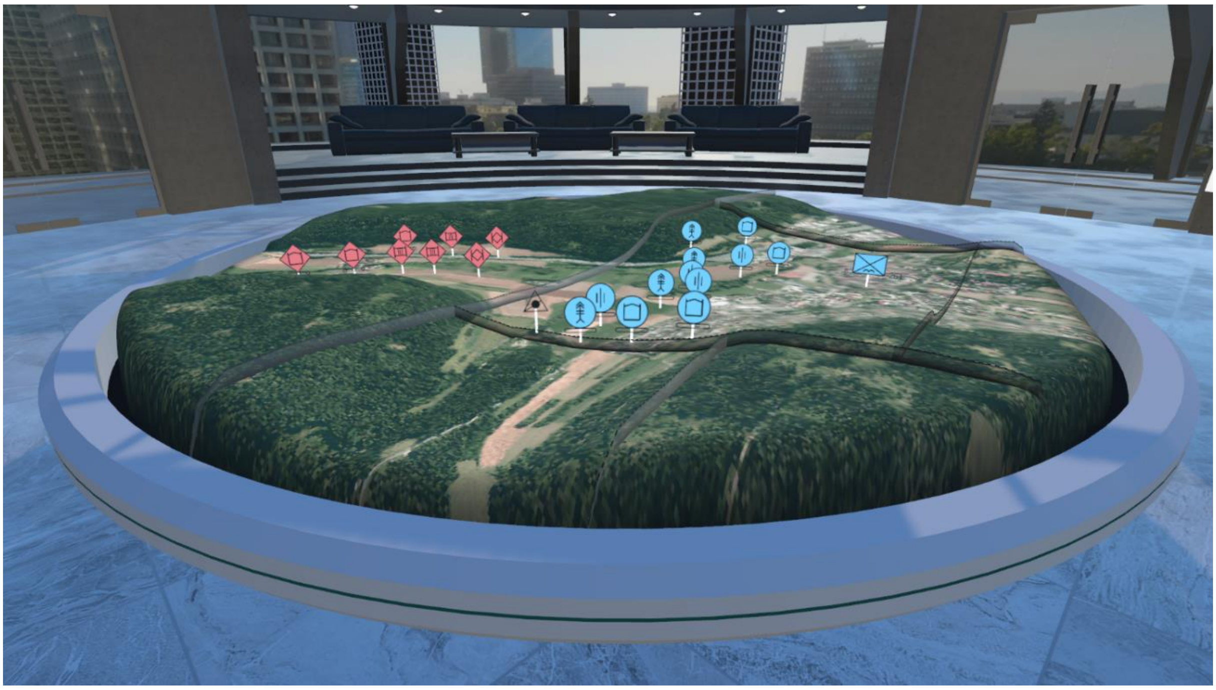

Figure 5: Digital Map table in Virtual Reality, displaying a satellite image on top of a digital elevation model and additional annotations as well as military symbols.

Figure 5 shows a satellite image on top of a digital elevation model, and – especially in VR – gives a good understanding of the geographic properties of the displayed area. It is, however, a 2.5D and not a full 3D visualization. Using actual 3D data an even more detailed display of geographic data is possible. Figure 6 shows an overhead view of the virtual table with actual 3D data of high quality. In this case individual buildings and trees extrude the surface of the table and allow for an intuitive display of the three-dimensional data.

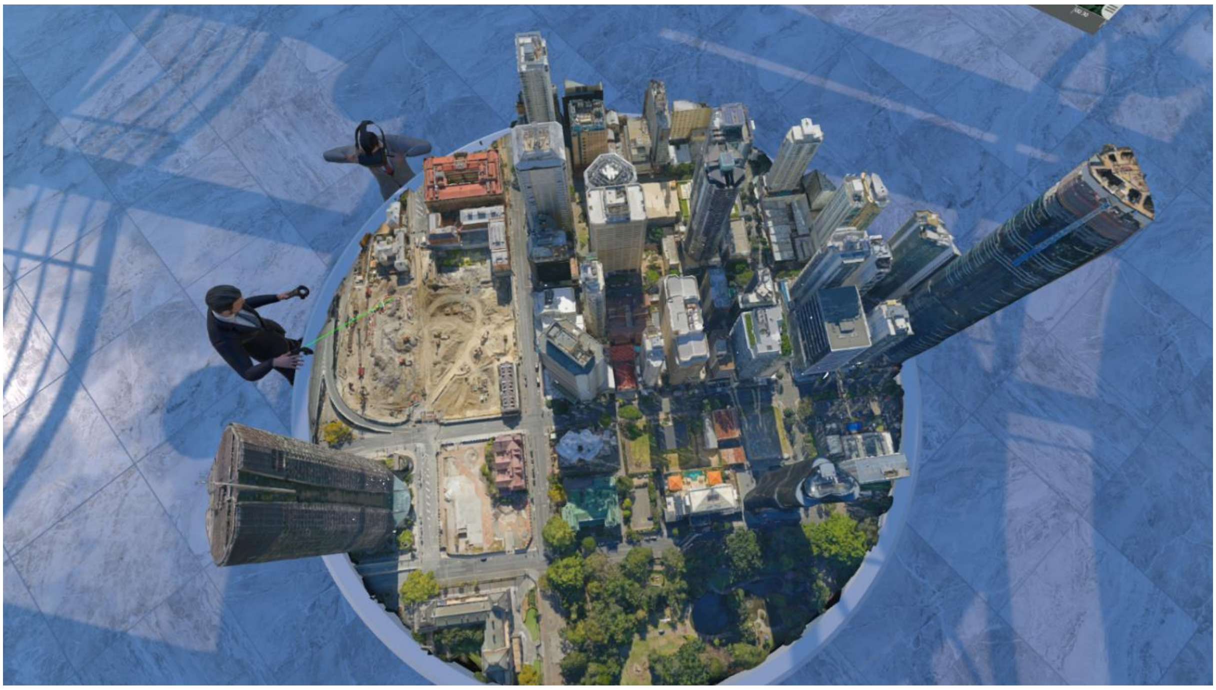

Figure 6: Overhead view of the Digital Map table in Virtual Reality, giving a sense of the buildings in 3D geodata extruding from the table.

4. COLLABORATION

Virtual Reality has the potential to bring users together independent of their respective physical locations. And it has been shown that remote collaboration in VR has no significant disadvantages to local collaboration in VR [10]. In the context of our virtual map table, we wanted to bring users together to be able to see the same information, interact with it and plan as naturally as possible. Natural interaction between people begins with the simple awareness of the presence of other people along with at least some basic information about their location. Using avatars to represent persons we are able to provide this basic information. While the location in the virtual world is arbitrary, the visualization of people at a certain location helps to understand their presence. Using information about the location and orientation of the VR-headset as well as the location and orientation of the controllers users hold in their hands, we are able to let avatars reflect the actual head pose and gestures a person makes. Since a common interaction for people at a physical map is simply pointing to some information on the map, this basic control of the avatar already allows a powerful and intuitive way to convey information in this setting. The users location in the virtual world is also used for directional audio. If a person speaks, everyone else in VR hears that voice coming from the corresponding avatar. Along with the head pose information (who is looking at whom) this provides for much easier coordination of the conversation compared to traditional conference calls or even video conference calls. Figure 7 shows gesture-based interaction at the map table with the addition of a virtual laser pointer which makes it easier to reach all areas of the rather large map table.

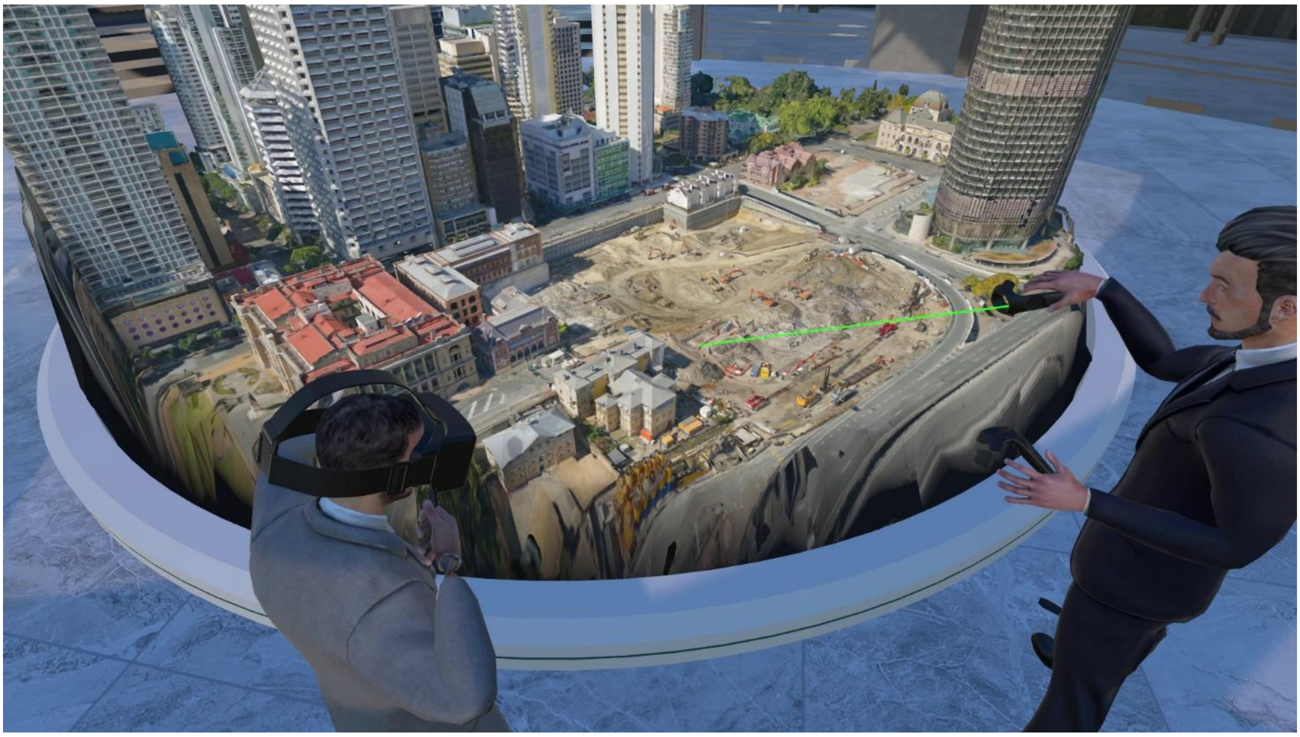

Figure 7: Collaboration at the Digital Map table in Virtual Reality

In addition to being able to point to information on the table with or without additional tools like a virtual laser pointer, the content of the table is fully interactive. Because the table shows a small part of the underlying globe (as described in section 3) it is possible to move the globe by grabbing it with a controller and moving it around and also to zoom in or zoom out by grabbing the globe with both hands and moving the hands closer together (zoom out) or further apart (zoom in). These interactions allow for a type of collaboration that is comparable to standing together at the same display even so participants may not be co-located with the addition of actual three-dimensional visualization of the data at hand. However, since this is a virtual world there are few limitations to what can be done.

A common part of planning is making decisions based on the available data. And while the virtual map table is able to display very detailed terrain information in 3D, standing around a table still gives a different impression to actually being on site. To enable users to get an idea of the actual surroundings, we added a so called ‘pedestrian mode’ which allows user to take a virtual walking survey and stand at any location getting a realistic idea of the surroundings for terrain assessment (See Figure 8 on the right).

Figure 8: Ability to ‘jump’ into the table and take a virtual walking survey.

5. REMOTE COLLABORATION

While any collaboration in VR always relies on a network connection and is therefore independent of the actual location of participants, connecting participants distributed over vast distances comes with additional challenges. Each participant runs their client and therefore creates an individual virtual world. To allow for collaboration all those virtual worlds have to be synchronized. Only if every participant sees the same information with regard to the virtual map table as well as the location and orientation of other participants, actual collaboration is possible. There are two major concerns with this kind of multi-way synchronization: bandwidth and latency. Since map data is usually not created on the fly, it is reasonable to assume that map data as well as assets such as the virtual environment, textures and avatars can be transferred beforehand and do not have to be continually synchronized. Data that actually has to be synchronized on-the-fly are the locations and orientations of the head and hands of each participant and the extend of the map currently displayed which can be described by the location of the center and a zoom factor. Of course, additional features may require additional data to be synchronized but the described information already allows the kind of interaction and collaboration described in the previous section. We can describe the required bandwidth as follows:

$$x = 30 * 16 * \left((n * 3 * 6) + 3\right)$$

Where x is the required bandwidth in bits / second for n persons assuming an update rate of 30fps, an accuracy of coordinates of 16 bit and three joints for each person, each consisting of three coordinates for its location and three angles for its orientation plus three coordinates for the extend of the map table (two for the location, one for the zoom factor). For 10 persons, this results in a required bandwidth of 0,087Mbit/s, which should not pose a problem for most communication channels. When it comes to latency, we have found that the kind of interaction described here can easily cope with up to a second of delay as it does not require quick interactions or reactions such as in computer games which has shown to make this kind of interaction possible via a satellite connection where a certain latency cannot be avoided.

6. CONCLUSION

We presented a system that utilizes a virtual reality environment to allow for cooperative and location-independent terrain assessment for deployment planning. A virtual table allows the display of three-dimensional geo-data which is well suited for collaboration. Being connected to a web-based version of the software, it is possible to seamlessly switch between widely used technology such as web-applications and new technology such as VR. This allows users to participate as long as they have a device that can run a browser. In VR, avatars provide an intuitive way for collaboration that provides a useful way of “face-to-face” interaction even if users are actually far away from each other. In addition to intuitive collaboration, the three-dimensional display of geographic data along with features such as the “pedestrian mode” which allows users to take a virtual walking survey and stand at any location, getting a realistic idea of the surroundings for terrain assessment are great advantages over conventional systems. Due to the kind of data that actually needs to be transferred for collaboration, bandwidth requirements are low and allow the system to work with a wide range of communication technology. In the future we plan to focus on interactions and functionality that is uniquely possible in VR as there is huge potential, such as shown in [11], to improve interaction and collaboration.

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