VIRTUAL REALITY FOR IMAGE INTERPRETATION

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ABSTRACT

This paper presents the concept and technical details for a "Virtual reality Image Exploitation Workspace" (VIEW) for use in e.g. aerial image interpretation. Virtual Reality (VR) and serious gaming can increase the learning motivation and outcome in image interpretation. We use our VIEW concept for a VR game-like assistance system to evaluate the learning-supporting immersion or presence level of image interpreters while solving typical interpretation tasks in VR. The problem statement centers on the realization aspects of a VR assistance system for image interpretation providing a high level of immersion. This work combines the setting of a real serious game for formal image interpretation training with virtual reality to increase the immersion level. We also examined the special requirements for image quality and formal workflows that arise from professional image interpretation. The presented VIEW concept deals with multiple aspects in respect to e-learning, professional training and virtual reality for image interpretation. Preliminary evaluation results from a realized prototype show the feasibility and user acceptance of the VIEW concept.

KEYWORDS

Virtual Reality, Immersion, Image Interpretation, Serious Games, Assistance Systems

1. INTRODUCTION

Serious Gaming and Virtual Reality (VR) have long since been an active topic in professional training (Mazuryk and Gervautz, 1996; Freina and Ott, 2015). With the currently available commercial off-the-shelf hardware these training applications and the research therein have seen a staggering increase (Ganbatte DevBlog, 2018). VR is especially well suited for immersive experiences. In combination with gaming, virtual worlds provide users with rich playable environments, welcoming playing, testing and learning.

The application area of our work is aerial and satellite image interpretation. The interpretation of aerial and satellite images poses a wide range of challenges because of different imagery sensor types, difficult image material or unknown objects. Professional image

interpretation is done in various fields, ranging from the microscopic level in medicine, e.g., diagnostics in histopathology, to the macroscopic level of aerial or satellite images, e.g., civilian applications like search-and-rescue, agriculture, oceanography, or military intelligence acquisition (Roller, Berger and Szentes, 2013). Image interpretation requires the detection, recognition, identification and analysis of structures and objects, according to a given task based on optical, infrared and radar imagery. Besides highly developed assets, sensors and image exploitation systems, the success of a reconnaissance mission depends on the interpreter's analysis performance. Special face-to-face training courses blended with technology-enhanced learning tools, such as e-Learning courses, simulations and serious games, ensure that image analysts are qualified to a high standard. Our application scenario focus on intelligent assistance and e-learning systems that help users to perform their work effectively and efficiently.

An immersive virtual environment can promote the motivation for continuous usage and therefore it can ultimately promote learning. A VR system with a high immersion capacity facilitates the sensation of presence, i.e., the sensation of "being there" (Riva, Davide and IJsselsteijn, 2003). The notion of immersion and presence often go hand in hand and several terms have been coined with subtle differences, e.g., immersion, presence, involvement, emotional response or degree of interest. In this paper, we use immersion as the technical form factor that features presence. Besides the motivational aspects of immersion or presence, there are further technical benefits for image interpretation, such as the efficient display of 3D data or spatial objects, ease of spatial cognition (Hubona and Shirah, 2005), virtually infinite space, or dislocated collaboration.

In the past huge efforts were needed to make spatial data tangible, e.g., by producing statuary, or by using 3D glasses for anaglyphic stereoscopic printing (red-green) or for 3D monitors. With VR one can immerse in a virtual environment and directly experience 3D.

In aerial image interpretation, the cognitive experience of the spatial data can have a considerable impact on the quality of the interpretation reports, e.g., when spatial relations could be experienced in more detail and with a natural access to reference scales. For example, VR can easily mediate topographic map data.

To achieve immersion we follow gamification and digital game based learning paths (Prensky, 2001). The combination of gamification and VR is obvious - as the entertainment industry proves with VR games numbered in the millions (Ganbatte DevBlog, 2018). In a professional (or serious) context, VR can be combined with aspects of serious gaming. A serious game is a digital game not just for entertainment but with at least one characterizing goal (Dörner et al., 2016), e.g., learning or training. In digital game based learning (Prensky, 2001) the game design is highly oriented at the target group and the learning objectives. A high acceptance for the game's assets and game mechanics promote the acceptance by the users which enables immersion, which in turn promotes the intrinsic motivation for playing or training, which positively influences flow and ultimately could increase the learning efficacy (Connolly et al., 2012).

The superordinate research question (and application scenario) of our work is how to optimally train and support professional image interpreters. This paper specifically addresses how to increase the immersion level in assistance systems for image interpretation using VR. The adjacent subquestion is how to design VR systems for image interpretation that fulfill the quality requirements regarding image fidelity, high resolution and optimal usability in a professional working context.

This paper is an extended version of the conference paper (Alexander Streicher, Julien Hoffmann, 2019). It presents the concept study and prototype realization of the *Virtual Reality*

Image Exploitation Workspace (VIEW), a VR assistance as well as a training system for image interpreters (Hoffmann, 2017). The realization targets commercial VR hardware and implementation in a VR capable game engine. The concept offers answers to some challenges that are specific for VR for image interpretations, e.g., image fidelity, interaction paradigms or display of high-resolution imagery.

2. RELATED WORK

Virtual Reality itself has long been an active research topic with multiple industrial appliances (Nomura and Sawada, 2001). The dome-like display for urban planning by Nomura et al. influenced our concept (Nomura and Sawada, 2001). Of further inspiration has been the work of (Streitz *et al.*, 2001); they analyzed how to build interactive office environments by integrating various display types. In some parts, this has influenced our concept, e.g., the design and placement of our virtual displays and interaction elements. Other driving work has been from the hierarchy of needs in VR development by Cronin (Cronin, 2015), with special focus on the factors interpretability (sense) and usefulness (value).

For image interpretation VR has been used for visualization geoscience data, e.g, by Lin et al. with a VR geoscience image interpretation workplace (Lin and Loftin, 1998). We followed also their Closed World Interaction (CWI) concept that influences the complexity – or rather simplicity – of intuitive VR interface design with low affordance. Such interaction concepts should be followed to benefit from VR visualization advantages (Loftin and Nelson, 2000), although no VR interaction standards exist yet (Malaika, 2015). A popular example of geo-visualization tool is Google Earth VR that allows the users to experience many places in detail in 3D (Käser *et al.*, 2017).

The advantages of using VR for visualizing high resolution image data in an immersive virtual environment has been presented by (Loftin and Nelson, 2000; Billen *et al.*, 2008). This is in line with other work which show that geoscience can benefit from VR interaction possibilities (Furumura and Chen, 2004; Ohno and Kageyama, 2007). A Study by Lackey et al. (Lackey *et al.*, 2016) show how positive VR experiences can reduce stress and workload. Such kind of immersive environments can optimally utilize the brain's cognitive capacity to process visual information (Hubona and Shirah, 2005).

3. VIRTUAL IMAGE EXPLOITATION WORKSPACE (VIEW)

VIEW is a concept for a VR assistance system for image interpreters which incorporates immersive elements suitable[1] for professional image interpretation. In this context an operational image interpretation assistance system, ViLand (Figure 1), has been used as a base model for VIEW. Such systems offer tools for image navigation, manipulation and annotation as well as specific reporting functionalities, e.g., standardized reporting processes and formats.

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[1]Suitable in this context means that the professional or serious context is being considered, i.e., less entertainment in favor of productivity.
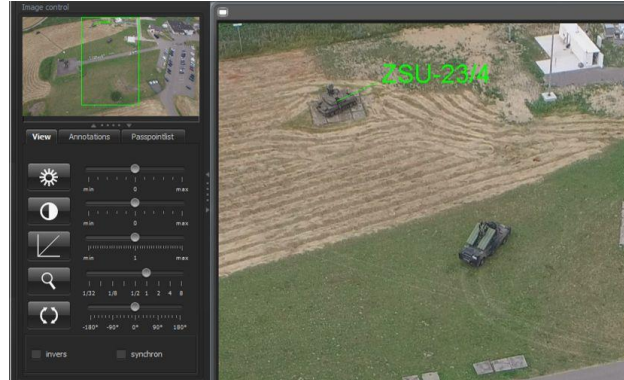
Figure 1. Assistance system ViLand for image interpretation and reporting

3.1 Challenges for a VR Image Exploitation Workbench

We did not simply try to make a VR game. Our goal is to exploit the advantages of VR (like inherent 3D experience possibilities) for its usage in professional application contexts, in our case professional image interpretation and image exploitation. Furthermore, we address the specific field of e-learning and training for image interpreters. Therefore, we also study how to achieve high learning outcomes using such kind of assistance systems for learning and training. One challenge in this context is to keep users motivated, i.e., a high immersion in the virtual environment should promote the willingness to keep on using the system and to keep up training or learning. In the context of this work with VR we asked experts about their reservations, and three main categories have been identified: effectiveness, technology and usability.

Effectiveness. How to achieve a high level of professionalism? How to exploit serious gaming principles to improve immersion and learning efficacy? In a professional context "playing a game" – even if it has been considered a "serious game" – typically does not directly count as a normal work task. In contrast to this are computer simulations which are used for training. However, computer simulations typically do not incorporate gamification aspects which help serious games, i.e., games with a characterizing goal (like as learning), to increase immersion and motivation and learning outcomes. Being serious and playful at the same time –as depicted in the oxymoron "serious game" (Djaouti *et al.*, 2011) – rises concerns in the professional context and is one of the main challenges.

Technology. Low initial and running costs are a decisive factor for a corporate widespread use of a system such as VIEW. Dome-like systems and even professional VR systems have been around for a long time now, but their high cost prevents them from being used extensively. In contrast to that is COTS hardware like the Oculus Rift or the HTC Vive (and their derivatives). However, what are the technological limitations, in particular in respect to image fidelity? What are the VR hardware limitations (e.g., headset weight, distortions of lenses, display resolutions, color bit depth, computing performance, etc.), and what are the software limitations (e.g., game engines, image filtering, software architectures, etc.)? Are commonly used game engines able to display giga-pixel imagery data without introducing additional unwanted artifacts, e.g., image compression artifacts? We addressed the hardware and software challenges separately. For hardware we examined how users perceive known VR artifacts in COTS VR hardware, i.e., we do not modify the hardware but we try to minimize their effects on the usage experience. An

additional challenge would be, of course, if we would try to replicate image quality in VR as known by professional displays. Currently, with normal COTS VR hardware this is not possible without major hardware modification (display and lenses). For software we propose to use a decentralized map-server based software architecture with tiled images (details in next section).

Usability. The effectiveness of the user interface is key. The questions asked have been how to achieve high usability and high affordance? How to find the best-suited VR human-computer-interaction (HCI) paradigms? The problem is that no commonly established VR HCI standards exist yet (Hoffmann, 2017) and existing principles from entertainment have to be transferred to professional contexts in a useable manner. Whereas some VR interaction ideas are helpful for immersion in an entertainment setting (like drawing a virtual bow), no one wants to do that for a long period of time (Hoppe, 2016), e.g., strenuous, sweeping arm movements to manipulate the virtual image display.

3.2 Virtual Image Display (VID)

For *image* interpretation, the Virtual Image Display (VID) is apparently the most important aspect. Based on requirements analysis with experts on aerial and satellite image interpretation the demands for a VR display comprise: high resolution, image fidelity, multi-channel imagery and image manipulation.

The VID is a virtual monitor where the imagery data is displayed, navigated or modified; it is VIEW's primary user interface (UI) component. In the game engine this is technically a dynamic texture. Various manifestations of the texture's underlying model have been discussed and evaluated (Figure 2): flat or curved plane, quarter-, half- or full dome, or 360 degree panorama. The objective is to maximize the visible display for quick and sound recognition. Although this leads to a half- or full dome or a 360 degree panorama, it is not the typical type of content in image interpretation. Also it necessitates ample head movements which hinders quick recognition and has the risk of fatigue (Hoppe, 2016). Dome-like approaches (Figure 2) inherently impose too much unacceptable vertical and horizontal distortions on the image data. Image interpreters require a reliable and undistorted display. Although a flat plane does not impose distortions effects on the texture (no curvature), it proved difficult for the users to view content in the corners for a big VID. This leads to a compromise: a curved VID (Figure 2). The curved model requires less head movements and can cover the peripheral vision.
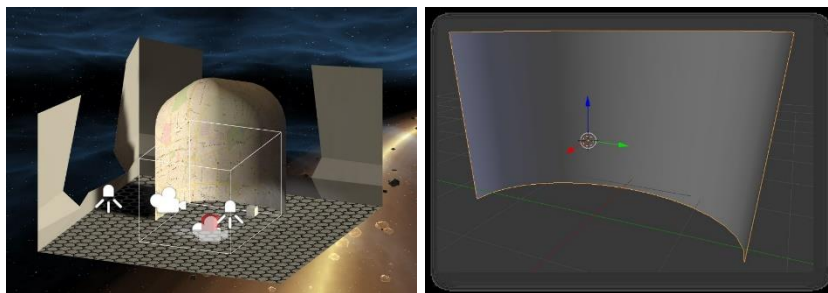

Figure 2. Display concepts. (left) dome-like display with avatar in the center; (right) curved display

3.2.1 High Resolution

The "virtual resolution" should be as high as possible to display as much content as possible. Professional image interpreters often use multi-monitor workstations for maximum display of image data as well as instant access to tools. Especially in aerial or satellite image interpretation with huge images or maps one monitor is used for maps, one for the tools (e.g., reporting tool), and the remaining monitors for displaying and working with one or multiple images, e.g., navigating, annotating, modifying, etc.

The challenge is to display huge image data that does not fit into the GPU memory. A typical aerial image easily exceeds 50 megapixels and 1500 MB. Today's game engines and GPU allow a maximum size of 8192x8192 pixels for a texture. Therefore, the image has either to be scaled (loosing details) or split up.

The solution approach is to use tiled rendering. We propose to use a software architecture (Figure 3) with a map-server, e.g., GeoServer[2], and a slippy map framework, e.g., UnitySlippyMap[3] for Unity3D. This enables the integration of various sources, e.g., vector maps, (geo-referenced) images, markers, etc.
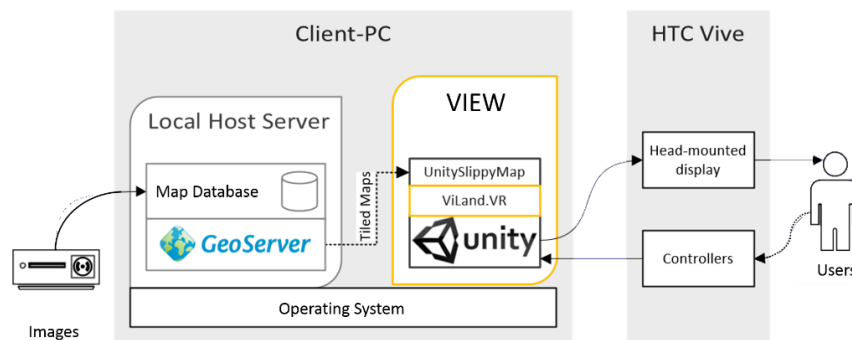

Figure 3. VIEW software architecture using Unity game engine and GeoServer for image tiling

3.2.2 Image Fidelity

The correct and sound image rendering and display is essential; the user acceptance towards the interpretation system highly correlates with the subjectively recognizable display quality. Professional image interpretation implements technical measures to ensure image fidelity, e.g., special hardware with higher color range (i.e., 10 bit per color channel instead of consumer 8 bit) or calibrated displays. Software measures include lossless compression or accountable metadata management, e.g., for validated documentation processes. The geospatial server approach solves this for our VIEW concept. In the rendering engine, image modifications (e.g., compression) must be disabled, and textures must have uniform, neutral-colored lighting.

Critical and not yet solved issues concerns the VR hardware, in particular the head-mounted display (HMD). Whereas continuous development shows an increase in the HMD display resolutions, some negative effects can still be seen (Anthes *et al.*, 2016), like the latency, screen-door effect, lens distortions, ring effects or light rays. We propose to lay the focus on the usability and the subjective acceptance level for the target group, e.g., by a pre-study and requirement analysis.

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[2] www.geoserver.org, open source mapserver server for geospatial data sharing.
[3] https://github.com/jderrough/UnitySlippyMap

3.2.3 Multi Channel Imagery Display

A further requirement is the possibility to display various types of imagery data, i.e., electro-optical (EO), infrared, radar and hyperspectral. Ideally, video streams should be supported as well. Important is the overlay aspect and geo-referencing. It must be possible to display the very same object or area in different visual channels but with identical alignment. For an area this means that the location of the overlaid images must be identical. The map-server approach solves this by providing access to different map or image sources which can be combined with overlay layers. In VR/VIEW the VID is just the window to the map-server and the layer switching is propagated to the server by means of standard protocols (e.g., web map service, WMS).

3.3 Interaction Concepts

Especially in a professional working context the interaction paradigms must be swift and without risk of fatigue, and, of course, the typical usability requirements must be met. In VR no commonly accepted interaction standards have been defined yet (Malaika, 2015; Hoppe, 2016). Analogous to smartphone gestures development the ongoing VR development will show which emerging interaction paradigms will succeed (Malaika, 2015). Table 1 summarizes some common interaction paradigms.

In general, commonly accepted usability principles like Fitt's Law provide helpful design guidelines. Fitt's Law states user interface requirements for fast and purposeful movements. A study by (Hoppe, 2016) shows that the UI must be quick, intuitive and easy to work with. We adopted the study's strategies in our concept. A special focus is on the workplace suitability, i.e., wearisome sweeping gestures risk fatigue, or the UI must be easy to find and use.

In our concept we focus on the HTC Vive hardware with two controllers. For the interaction with the VID the principles from gesture and smartphone interaction are followed. Display translation can be done via pointing a virtual "laser pointer" and using a controller button dedicated for "left-click" and moving the controller in the designated direction. This is similar to smartphone interaction for moving the display content with one finger. The operations for zooming/scaling and rotating are analogous, i.e., moving controllers apart for zooming, and rotating one controller around a fixed controller for rotation.

The tools must always be ready and easy to use. We propose to adopt the interaction-cube idea from Google Tilt Brush[4]. It should provide easy access to the most common operations, like layer selection, image or scenario reset, contextual assistance.

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[4] www.tiltbrush.com, 3D painting VR application useable with motion controllers.

Table 1. Overview of some common interaction concepts from arbitrarily selected example VR applications

Concept	Manifestation	Example
Locomotion		
With teleportation	Point-to-teleport	Vivecraft
	Teleportation with sphere	The Lab
Without teleportation	No teleportation	Keep Talking
	Float using touchpad	Google Earth
	Walk using touchpad or controller	VR
	Walk (room-scale)	Subnautica
		The Lab
Interaction With Images		
Zoom	Head movements	Keep Talking
	Stepwise by area selection	World of
	Dragging finger on touchpad	Comenius
		Batman VR
Pan / move	Press and drag	Google Earth
	Head movements	VR
		VR Cross View
Manipulations		
Extended functionality	One hand activates functions for other hand	Tilt Brush
	Separate console	Subnautica
Text input	Speech recognition	Starship Cmd.
	Large virtual keyboard	VR
		Onward
Object manipulation	Controller grip and movement	Nvidia
		Funhouse

4. APPLICATION

We have verified our concept in a prototype which we implemented using the Unity Game Engine (Figure 5, Figure 6). For the VR integration with the HTC Vive hardware we used *Steam VR* and the feature rich *Virtual Reality Toolkit*[5] (VRTK). To increase the immersion level we implemented the elements of the VIEW concept. This includes scenery, display and interaction paradigms. Gamification aspects involve the integration of assets from a serious game for image interpretation (Atorf, Kannegieser and Roller, 2019). We adopted the original game's science fiction setting which plays in space in a far future. The virtual image interpretation display is placed on the game's spaceship bridge, but whilst the original game itself has a fixed camera position, in VIEW the player is able to move around and play with various elements of the virtual bridge. Lighting and arrangement of the assets are congruent to the original game that has been developed in close cooperation with the target group of image interpreters. To further increase immersion, we added ambient "sci-fi bridge" background sounds.

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[5] https://vrtoolkit.readme.io, a collection of scripts for Unity3D for VR development.

Figure 4. Bridge scene of the serious game "Lost Earth 2307" (© Fraunhofer IOSB) (Atorf, Kannegieser and Roller, 2019)

The virtual image display (Figure 6, left) is curved to completely match the field of vision of the players - if they stay directly in front of it. To fulfill fidelity requirements the virtual display lighting is uniform in neutral white, i.e., no spots, no colored light, no shadows. Especially for radar images this is of high importance because of the black-white nature of the image material.

As explained in the VIEW concept we decided against a 360 degree virtual display because of the increased movements efforts and risk of fatigue. This also holds true for a virtual dome. The virtual display is a curved texture with a slippy map image tiling approach. When the user interacts with the texture, it is modified accordingly, e.g., translation, rotation or scaling. The use can select the type of image on the interaction cube, i.e., switch between the various layers of the underlying map-server to display different image channels for the displayed map location. In the VIEW prototype users can compare three different image channels, i.e., select between a vector map from OpenStreetMap.org, a high-resolution optical satellite image, and a radar image (Figure 7). In our example setting each image channel displays the same location, the Aswan High Dam in South Egypt (Figure 7). One of the challenges for realizing the prototype was to find usable image material from the same location that met the quality requirements (e.g., up-to date or almost identical recording time, high resolution, integrity, etc.).

For gamification, the image interpretation tasks are aligned to a storyline which deals with the Aswan High Dam and sabotage actions of fictional rebels. Users must solve image interpretation tasks, e.g., locate rebel camps or analyze road networks, to help the local authorities capture the rebels. In the training scenario additional challenges have been introduced to adjust the difficulty and cover all learning objectives, e.g., clouded high-resolution optical images which prompt the users to switch to radar imagery which is not affected by atmospheric conditions. Further gamification aspects include competitive components like achievements and high-score boards.
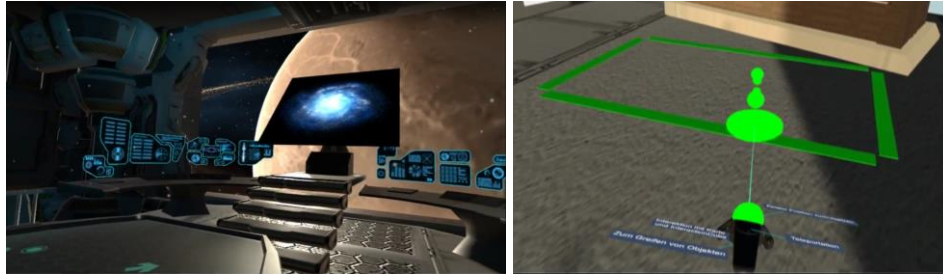
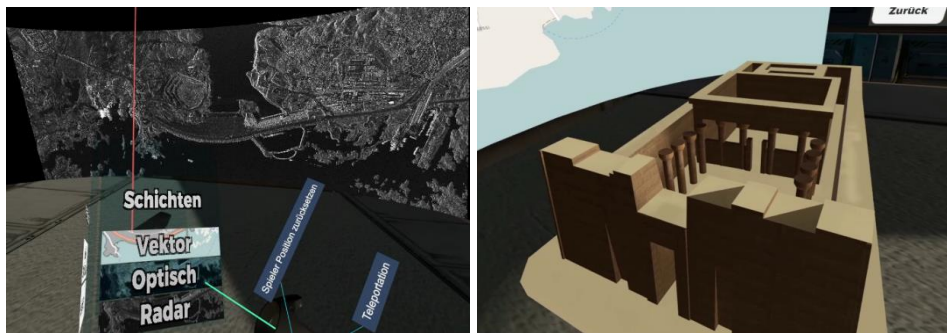Figure 5. (left) VIEW scenery, sci-fi bridge setting; (right) movement by teleportation

Figure 6. (left) VIEW prototype with bridge scene, teleportation interaction, and curved display for maps and images. (right) 3D model interaction mode
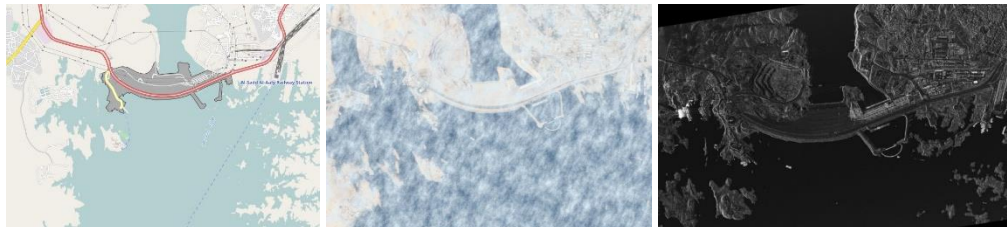

Figure 7. Identical location (Aswan High Dam) but different image channels: (left) vector map, (center) clouded optical image, (right) radar image

5. DISCUSSION

A preliminary evaluation of the VIEW prototype with n=16 users (average age 35, 14 male) showed an overall positive acceptance rate and good presence level. The game elements have been evaluated positively and as beneficial for immersion. Also positively evaluated were the 3D modes (Figure 6, right), the different image layers and that the user always is in control. Of negative impact was the grip interaction; the location of the button on the HTC Vive controller was unclear to the participants. Table 2 shows positive and negative statements (translated from German). The results indicate that image interpretations can benefit from VR

by increased immersion (e.g., by gamification or spatial presence) and by experiencing spatial content or 3D objects in a more natural way.

Table 2. Positive and negative responses to VIEW

Positive	Negative
I felt comfortable on the bridge. I'd very much wanted to continue walking there all the time.	*My hands are not to be seen, that would be cool - I do not know if that's possible.*
The game elements were fun and motivated to carry on with the task.	*The sound does create a higher immersion, but I'd like to have my rest at work.*
Interaction with map was super! Scaling as intuitive as expected. It was super that the map got caught exactly on the [pointing] ray.	*Grip is difficult because the button on the controller is placed oddly.*

A systematic evaluation is going to study the VIEW concept along the dimensions user acceptance, immersion, image quality recognition, and image interpretation effectivity and efficiency (including usability). The hypothesis is that VIEW offers effective and immersive support for image interpretation tasks and helps in training image interpreters. The questionnaires of interest for us are the Igroup Presence Questionnaire (IPQ), the System Usability Scale (SUS) score (Brooke, 1996), and RawTLX to measure workload. A Web-browser 2D replica is going to serve as a reference model. The replica will mimic most of the features of the VR prototype but obviously address presence and immersion at a different level. Users can familiarize themselves with VR interaction and settings in a tutorial level (Figure 8), which includes most of the later on tested elements of the VIEW prototype. Experiments on the perceived conspicuousness of VR artefacts (like screen door effect, ring effect, lightray effect) showed that the negative effects by them on perceived image quality and immersion are lower than expected. The influence of artefacts can be reduced by a correct VR headset setup, e.g. by individual adjustment of the straps and by an individual adjustment of the interpupillary distance (IPD) setting of the VR headset. We use an online IPD tool to determine the correct value for the IPD (Figure 8).

Figure 8. Study setup. (left) VR tutorial level; (center) interpupillary distance measurement (IPD tool); (right) room-scale setup for the study

6. CONCLUSION

This paper presents the concept study for a VR assistance system for image interpretation (Alexander Streicher, Julien Hoffmann, 2019), the *Virtual Reality Image Exploitation Workspace* (VIEW). The application field is aerial image interpretation, i.e., detection, recognition, identification and analysis of structures and objects, according to a given task based on optical, infrared or radar imagery. The concept study explored various approaches for virtual displays as well as interaction paradigms matching the demands for professional image interpretations. Our concept proposes a virtual environment enriched with game elements to increase the immersion level. We propose a software architecture for tiled rendering to display high-resolution imagery data. Gamification elements like real assets from a congruent serious game, an instruction story, or the possibility to explore the environment promote playability and immersion. The architecture includes a slippy map module and a server for geospatial data, e.g., the open source map-server software. This approach allows including interoperable image data, labels, annotations, etc. from various sources.

ACKNOWLEDGEMENTS

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