Applicability of Virtual Environments as C4ISR Displays

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ABSTRACT

New sensors, communication infrastructure, and information systems will make plenty of information about actual mission scenarios available. Innovative concepts like Network Centric Warfare (NCW) describe the consequent availability of this information for each command level at any time, at any place. But the huge amount of information may also lead to information overload for the human commander: Relevant information may be overseen. This might results into building a wrong mental model of the mission scenario and wrong decisions. Therefore, the development of new display paradigms and technology for information presentation is essential. They should be based on established procedures in military decision making and staff planning and allow the easy transfer of them. This article presents some example approaches of applying Augmented Reality (AR) and Virtual Environment (VE) technology as advanced Tactical Situation Display (TSD) for different military command levels. It is concluded that research on microergonomic (i.e. perceptual, motor capabilities for data visualization and data input) and macroergonomic topics (i.e. workload, situational awareness, decision making performance) is needed for a reasonable application of VE as a display of C4ISR systems.

1 TACTICAL SITUATION DISPLAYS (TSD)

The main function of a TSD is to display the current situation and location of own and reconnoitred oponent troops and facilities. It is used for tactical planning of intended future operations. Quantity and quality of situation data are essential for an adequate operation planning. A basic TSD consists of scaled maps of the regional properties of the mission area displaying all relevant information and intentions. It allows a brief overview about tactical and regional situation for the specific mission commander and higher command levels. The main parts of the TSD are: Regional situation, including geo-referenced terrain and feature data; forces' strengths and locations; missions' sections and foci; areas for mission support and control. This information is usually coded by a special tactical symbology.

1.1 Today's Tactical Situation Displays

Today there are mainly two common types of TSDs. The first one, shown in figure 1, is a command post in the field. The TSD used here works by means of map, paper and pencil. Actual information is transmitted by radio or field telephone and manually drawn into a map. It is obvious that in time-critical processes with large amounts of rapidly changing information an overload of the operators is very likely. The display may not show actual or valid information then. It is likely that the operators will be busy with keeping the display up-to-date instead of decision making. However, such a display has the advantage of

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being fielded so that the commander is in the field: This will induce situational awareness. The commander experiences the terrain elevation, terrain feature, weather, etc. and knows "what is really going on" during the mission.

Figure 1: TSD at Command Posts "n the field".

On the other hand there are TSDs at operation centers, as can be seen in figure 2. The centers are usually more ore less distant from the mission so that commanders are not put at risk of combat. Tactical situation data is pre-processed and computers are used to visualize the results. The advantages of these TSD's are (1) actuality of data, provided that the communication infrastructure is fast enough, (2) different views of levels of data aggregation, and (3) possibilities to include additional mission information.

Figure 2: TSD at (provisionary) Operation Centers.

However, one disandvantage of these TSDs is a very abstract presentation of mission data. Today's displays apply two-dimensional monitors or projection walls, which are sometimes difficult to operate. Display of information (projection) and planning environment (card table) is often not the same and requires additional information processing. Consequently, a combined mission display and planning environment should be achieved. Displays shoul make better use of the human perceptive, cognitive, and motor ressources.

1.2 Future Mission Scenarios and Requirements

Future military scenarios will be characterized by a diversity of mission objectives and tasks. They have changed from a purely military domain to areas like peace supporting and peace keeping operations as well as humanitarian aid in a widely unknown area and environment. Actual concepts like Network-Centric Warfare (NCW) include huge amounts of highly dynamic information, which will be available in any imaginable scenario [1]. Although data processing might become automated to a special extend, decisions will still be made by human operators. This requires advanced display and support systems for the decision making process. They have to support the human commander in cumulating a variety of diverse information for creating a correct mental model of the current situation. With this massive amount of rapidly changing information, relevant information may be overseen in time-critical situations. These perceptual errors can easily result into a wrong situational mental model and consecutive wrong decisions. It is not necessary to point out that wrong decisions may easily lead to extensive, sometimes fatal consequences. It is necessary to apply advanced system interfaces that make use of the human perceptual, cognitive, and motor capabilities. This way the amount of transferred information can be enhanced and the understanding of complex mission scenarios is supported.

When examining the applicability of special display technology there are several requirements to be considered. They refer to a functional and technical context.

A functional requirement is the consideration of the mission context and responsibility of the user. Each user or commander has special responsibilities and a designated role for mission execution. He should be provided with the important information only and not be distracted by other. This concept is further specified by the Common Relevant Operational Picture (CROP). CROP is a presentation of timely, fused, accurate, and relevant information that can be tailored to meet the requirements of the commander [2]. Even though actual missions are often carried out with a “slim” command hierarchy, each commander still has designated responsibilities. The concept of need-to-know has to be considered when selecting relevant information and type of presentation. Higher command levels are usually not interested in detail information, e.g. special terrain and vegetation features. But these would be important for low command levels and platoon commanders.

Another functional requirement is the intention and goal when using the display in decision making and mission planning. An obvious intention would be to collect relevant information about the actual mission. This requires a simple, one-way information transfer only. But often decision making requires additional mission analysis and supporting functionality. In this case interaction metaphors and techniques have to be applied.

In addition to these functional requirements there are several technical requirements. Usually high-level decision making does take place in stationary command posts with a lot of IT-infrastructure and communication lines. In contrast to this, low-level decision making is done in a distributed, operational scenario with few portable or no IT-infrastructure. These settings result into different requirements for portability and mobility of the display. Another, more practical requirement is the light situation of the display’s environment. Only few projection technologies would work under daylight conditions; most require a darker environment. There are several other technical requirements on safety, robustness, etc. exists which limit practical applicability of AR and VE technology as TSD. They have to be considered in addition to special visualization and interaction characteristics.

2 APPLICABILITY OF VE-TECHNOLOGY FOR C4ISR

There are various studies about the applicability of AR and VE -technology in C4ISR. They can be divided into two large groups. The first group consists of concepts and long-term programs including AR and VE. It is a high level, political approach, which is very mission-oriented. The second group is characterized by more concrete AR and VE-projects of laboratories. The approaches of this group are typically technology-oriented.

The Swedish system ROLF would be part of the first group. Its goal was to determine new possibilities of applying VE-technology for mobile command posts. It included a semi-immersive VE-system as a tactical situation display. The display was used to visualize positions of own and opponent troops, locations of important institutions, and terrain and weather data from different viewpoints. Additional data processing was used to assure that only important information was visualized to prevent distraction of the operator [3]. Another, long-term program is the Command Post of the Future Program (CPoF) of DARPA [4]. The overall goal of this program was to foster the decision making process with ongoing reduction of the staff. The program included an interactive, three-dimensional visualization, three-dimensional interaction with computer-generated objects, presentation of inaccuracy and probability, integration of dynamic factors, three-dimensional symbolic, integration of natural language processing and integration of knowledge-based systems.

The second, more technology-oriented group of approaches is more common. Institutions and laboratories working in this area use a variety of different AR and VE-technologies. The setups are often reconfigured for different research projects and analysis. For instance, the US Naval Research Laboratory (NRL) has developed an advanced battle planning and management system. The system included a semi-immersive display and multi-modal interaction. It was found to be suitable for virtual-prototyping, interactive mission planning and increasing situational awareness [5]. Similar approaches, like Mirage of the Army Research Lab (ARL) [6], the Visualization Architecture Technology (VAT) of the Crewstation Technology Laboratory (CTS) [7] or the Electronic Sand Table of MITRE Corp. [8] also applied projection-based VE-technology as described in a later chapter of this paper. Other approaches applied individual VE [9, 10]. But despite these operational approaches, education and training in this field is still using traditional media.

2.1 Command levels and proposed VE-displays

Based on the functional and technical requirements of section 1.2 we have proposed the application of various TSD systems and technologies for the different command levels as shown in figure 3.

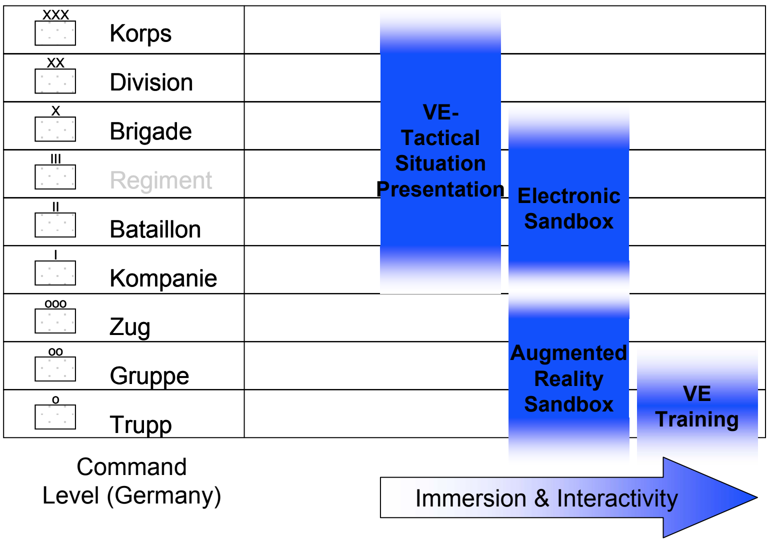

Figure 3: Command Level and Proposed TSD System.

The displays specified here are characterized by special functionality, portability and interactivity. On setting up this sketch, it was postulated that decisions on lower command levels require mobile or portable systems, i.e. AR systems. More massive, stationary displays can be used with higher command levels.

Moreover, a darker light environment is usually difficult to achieve for lower command level, whereas it is no problem in operation centers.

2.2 VE-Tactical Situation Presentation

For higher command levels the TSD is used to display relevant data and support the presentation of the tactical situation for expert staff members. Therefore, a presentation metaphor can be applied. A vertical 3D-stereoscopic projection can be used as a display. It visualizes geographic terrain data and tactical situation data. The terrain data is derived from military terrain and elevation data, which is available in high resolution for relevant areas-of-operations. The tactical situation data is delivered by a C4ISR-system. This setup is illustrated in figure 4.

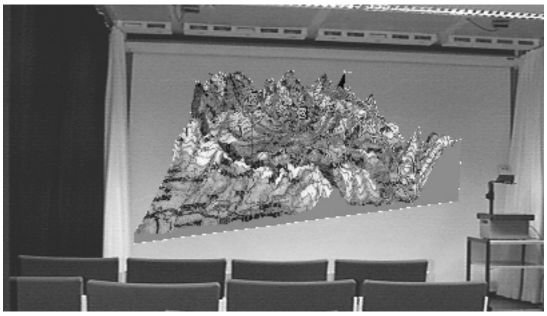

Figure 4: Interactive, 3D Stereoscopic Visualization of C4ISR-Data.

The presentation is interactive, so that the point-of-view can be adjusted and modified. Interesting subsets of the scenario can be enlarged in order to present details. Alternatively, a more global overview of the situation can be displayed. Further functionality includes hiding or adding information by sending the according requests to the C4ISR-database. Interaction was implemented in different ways. A standard PC-mouse allows a desktop-like interaction for navigation or activating of drop-down command menus.

Because it was observed that an audience often had difficulties following these actions, speech recognition was integrated into the system. In this case, the presenter controls the systems by a set of command words. This addition increased the understandability of the actions. The setup is based on available technology, so that it is possible to integrate it into existing training concepts with little efforts.

2.3 Electronic Sandbox

For more interactive applications like mission planning new media are necessary. In case of the Electronic Sandbox (ElSa) at FGAN/FKIE a military sandbox as used for training military decision making served as interaction metaphor. ElSa was developed as an advanced display for tactical information in mission planning, control and rehearsal [11]. The setup, as shown in figure 5, is very similar to the educational sandbox. In this case, a real model is used to present special scenarios in a more realistic way. It gives a birds-eye view of the situation of their own and opponents units and is very useful for illustrating strategies and tactics. We used a semi-immersive horizontal projection table to implement this metaphor [12]. An image is projected onto a horizontal projection plane. Like with a real sandbox, team members can sit or stand around the display and work with the synthetic terrain as if it was a real model.

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Figure 5: Sandbox Education (left) and Electronic Sandbox (ElSa) (right).

2.4 Augmented Reality Sandbox (ARSa)

The ElSa setup was primarily designed for a stationary use in operation centers. The support of commanders of operational units and platoons requires a more mobile and portable technology. In a subsequent research project a prototypic system for applications in-the-field was developed. It is based on the same software framework as the previous two systems, but applies technology from the field of AR. The system includes an individual head-mounted display (HMD), notebook and special interaction devices. A camera mounted on the HMD captures the real world video-images. The digitized images are searched for special patterns called markers. If a marker is detected, the software calculates its relative position and orientation to the user. A virtual object is then correctly placed onto the marker and embedded into the video stream. The combined scene is visualized on the individual HMD. Figure 6 illustrates the general idea of the system.

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Figure 6: Mission Briefing in the Field (left) and with the ARSa (right).

Interacting within AR applications is more difficult than in VEs because this technology extends the real world with virtual objects. Hence, a developer of an interaction metaphor has to find a way to manipulate virtual objects with real interaction devices. Many approaches have been made over the last years and the current direction is clearly direct interaction with the virtual parts of the scene. But direct interaction brings along certain disadvantages like extra tracking of the input device, user's mobility constraints caused by wired input devices or occlusion of the markers. Once a marker is occluded and no other compensation for this state is implemented (i.e. special pattern recognition for partially occluded markers) the virtual objects disappear from the scene and interaction is impossible.

With respect to the facts mentioned above, a method for an indirect input device was implemented. By mapping a portable 2D input device correctly into a virtual 3D scene a consistent interaction with virtual objects is achieved because the interaction tool will never occlude a marker when a user is trying to manipulate the virtual object. The cursor that is projected into the 3D scene is displayed as a virtual 3D pointer. Furthermore, using a common 2D input device does not require extra training for a potential user because nowadays almost everyone is used to work with a standard PC mouse. Another benefit of this approach is that it does not require any calibration of input devices or manipulation of camera parameters. The software framework which is used for the AR application as well provides the opportunity to integrate more than one AR client into the existing application. The distributed architecture allows multiple users to work in a collaborative AR application.

This collaborative setup can also be equipped with the proposed interaction metaphor. Each user can handle its own input device without distracting the fellow users. In order to improve the cooperation it is desired that each user is always aware of the position of the corresponding virtual pointer. This is guaranteed by initializing the different pointers with different colors, sizes or shapes. Hence, each user is always able to determine the position of virtual pointers which improves the performance in a collaborative task.

Collaboration in this distributed application is supposed to be very intuitive because it is always possible to see the team members, to talk to them as well as to see their interaction with the virtual objects at the same time – without any time delays. As a matter of fact it is also possible to integrate voice control into this setup.

2.5 VE-Training

For a successful mission execution a high level of training is required. Today's education and training concepts include lectures and literature for transfer of theoretical knowledge and exercises in designated training areas for the transfer of practical knowledge. Innovative media like Virtual Environments are considered to combine the benefits of both. They are flexible for presenting a broad range of scenarios, and they facilitate a realistic presentation with natural interaction. Moreover, they offer functionality for the integration of actual C4ISR information data so that it is available for operational mission preparation as well.

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Figure 6: Live-Simulation in Bonndorf (Hammelburg) and in VE.

In this case the training itself can rely on actual mission data as training scenario. This is very promising for training efficiency and training transfer. However, the media and display systems range from simple

COTS-PC-Systems to high-tech immersive VE-systems. In an actual project described briefly in section 3.2 we analyzed characteristics and effects of the applicability of different displays with varying degree of immersion on transfer of navigational knowledge.

3 ERGONOMICS AND HUMAN FACTORS

Relevant human factors for designing a VE-display system issues are manifold. They span a range from open microergonomic questions in the areas of visualization and interaction to open macroergonomics issues, including multi-factor phenomenas like information processing workload, situational awareness, training transfer, and simulator sickness.

3.1 Microergonomic questions

The term microergonomics usually refers to product ergonomics on a basic level. In case of a VE-system, this basic level subsumes analyses of visibility and interactivity. Both topics have to be analyzed for each special display system in order to obtain relevant reference data. In our experiments we have studied special areas of visualization and interaction with a special focus on the Electronic Sandbox and the Augmented Reality Sandbox.

3.1.1 Visualization and Interaction at the Electronic Sandbox (ElSa)

In real environments, depth cues like perspective, size difference, occlusion, shadow, accomodation, convergence and disparity facilitate an exact depth perception in near, medium, and far range. Depth perception in VE differs from reality [13]. Main differences have their origin in characteristics of the tracking and rendering system (e.g. latency, inaccuracies), the display itself (e.g. resolution, update rates), or even in visual deficits of the user (e.g. amblyopia, contradicting depth cues). They may lead to limited or impossible depth perception in VEs and introduce additional ocular stress.

A first experiment was performed to analyze the effect of rendering on visual depth perception. As not all aspects of rendering could be included, four types of rendering, respectively display types were specified in advance of the experiment. The intended application of terrain visualization led to the consideration of wireframe and map texture. Head-tracking (motion parallax) and stereoscopy (binocular sight) were added as further display options.

Significant effects of stereoscopy ($F=13.6$, $p<0.01$) and map texture ($F=11.4$, $p<0.01$) on stereoacuity were found. Stereoscopy improves and map texture reduces depth perception. With regard to reaction time, a second 4-way repeated measures ANOVA revealed significant effects of texturing ($F=7.8$, $p<0.01$), head-tracking ($F=5.7$, $p=0.03$) and stereoscopic rendering ($F=5.1$, $p=0.03$). For wireframe no significant effect is detected ($F=0.16$, $p=0.69$). These findings prove the benefits of stereoscopic data presentation in contrast to an accumulation of 2D-displays with elevation information (e.g. by color coding). This is especially important for presenting complex additional textural or color-coded information. In this case stereoscopy brings benefits for depth perception and helps to prevent perceptual overload.

Due to stimulus thresholds for depth perception different limits for stereoscopic depth perception exist. The goal of a second experiment was to determine these limits of a stereoscopic workbench in a display-fixed coordinate system. The experimental procedure for determining the display limits was a modified method of constant stimuli, which is frequently used for stimulus threshold analysis. The experimental virtual scene setup consisted of five objects in the same fixation plane. One of these objects was prominent to the others. As a second factor, the distance between fixation plane and projection plane varied. Subjects were instructed to react as soon as they detect the prominent object and afterwards to enter the result. This result was taken as measure for depth perception performance under the specific experimental condition.

For determining the maximum stereoacuity a significant effect of the distance between fixation plane and projection plane on stereoacuity was found ($F=30.6$, $p<0.01$). A subsequent trend analysis specified a linear relationship ($F=74.6$, $p<0.01$). With regard to the maximum distance before desegregation of the picture, a significant effect was determined as well ($F=5.4$, $p<0.01$). A subsequent trend analysis showed a linear relationship ($F=29.3$, $p<0.01$). For the fixation plane meeting the projection plane a maximum limit of am=0.43 m (s=0.06 m) for object elevation was found. At a maximum fixation plane elevation of 0.96 m above projection plane no depth separation was possible. The maximum stereoacuity deviated between am=0.08 m (s=0.04 m) and am=0.17 m (s=0.09 m), dependent on the distance between fixation and projection plane.

For activities at stereoscopic projection table a high ocular stress is expected, possibly resulting in serious negative after-effects on the visuals system of the user. For this experiment subjects processed a visual screening test before and after the two experiments described before. These experiments took about ½ hour and were characterized by difficult stereoscopic viewing tasks close to depth perceptional thresholds. Due to this, a high visual workload resulted. The viewing screening test used in this experiment has been standardized by DIN 52880 and G37 respectively [14, 15]. The first part comprises visual acuity and the second part several tests of binocular sight. Based on their values, ANOVAs show no negative visual after-effects for ½ hour of activity at stereoscopic projection tables.

These findings support the usability of stereoscopic projection tables for the visualization of geographic information, as long as special display bounds are considered.

Implementation of interaction into a VE system is possible in various ways. For this application, manual interaction was investigated. It can be implemented either by direct or indirect control, thereby using different interaction devices. For the analysis of the type of control (direct, indirect), interaction device (pc mouse, space-mouse, flying mouse, pen, grasp handle), and type of handling/grasping experiments were conducted.

Looking at performance measures and ratings for the 3D interaction devices, there was a clear distinction of interaction devices based on control type. In each of the three movement phases (target selection, command selection, backward movement) devices with direct control (direct DOF-cursor, direct DOF-ray, stylus A, stylus B, grip handle) facilitated better performance, that means shorter movement times, than those with indirect control (indirect DOF-cursor, indirect DOF-ray, velocity cursor, SpaceMouse™). In contrast to this there were no significant differences between interaction devices within the same control type group. The same was true for the subjective rating. As a result, for the same control type it did not matter, which interaction device to use or what kind of grip is applied; fine tuning or design of the specific interaction device had no significant effect on performance. On the other hand, for the same interaction device it was important to apply direct control rather than indirect control. This improves performance significantly. A reason for this result was that direct control was more consistent than indirect control. In case of a stylus, the virtual "laser beam" extended a real stylus and no visual or logical breaks are perceived. Consequently, no additional cognitive resources were required to map motoric output and system response. The missing differences between interaction devices of the same control type could be based upon the relatively small differences in handling or grasping, which are too small for operators to recognize. However, they could be of interest for long-term studies looking at periods of e.g. a whole working month.

It should always be carefully checked if the interaction within the application cannot be implemented using a simple 2D input device as a PC mouse. This would mean no performance or handling losses in comparison with 3D interactions devices. For applications requiring 3D input, direct control with consistency between interaction device and virtual counterpart should be implemented. Indirect control should be avoided when possible. According to the results of this study, special handling, grasping, or design of interaction device brings no additional benefits for performance or subjective handling.

3.1.2 Interaction at the Augmented Reality Electronic Sandbox (ARSa)

Providing interaction capabilities is crucial for state of the art AR-applications. Many different ways of interacting have been defined and implemented over the last years. However, the influence of certain technical characteristics of a typical AR system has hardly been investigated. Such system properties can cause tracking errors and latency. They strongly affect the interaction as well as the overall usability of such an application.

A common real-time AR system provides approximately 25 frames per second (fps) so that the user will hardly notice single frames in the video stream. As this is the regular case, 25 fps is one value for the frame rate that is analyzed. A slight lower frame rate of 18 fps was chosen to analyze the impact of a situation when a complex virtual object is rendered and the application needs extra computational time. The last fps-value to be studied was set to 8 in order to test the effect of a very slow AR system on the users. For the intensity of a jittering object also three values were chosen for the first experiment. The first one should be clearly no extra jitter added to the system. A slight boost of the jitter (medium value) was to be analyzed in a second test and the last parameter was also set to a value that resulted in a relatively strong jitter of the virtual map. Preliminary tests showed that the third and highest jitter value made the second experiment almost impossible to complete so only the low and medium jitter was used.

Two different experiments were designed in order to specify the effect. The first one consists of a simple selection task. Three position landmarks (spheres) of different sizes and colors appeared on the map and the user was instructed to target the sphere with a certain color. Afterwards, the spheres were relocated on the map. As soon as the user selected the correctly colored sphere again, a selection menu was opened and he had to select the correct color. The second experiment was basically about the transfer of real information into the virtual object. The user had to look at a real map (captured by the camera). The task was to transfer the information from the real map correctly into the virtual map as fast and correct as possible.

The results show that even low frame rate does not have a strong impact on the performance. It is slightly worse than a real time system. A significant influence on the accuracy and time does only have the jitter. The medium and the low jitter value achieve almost the same performance. But the highest jitter strongly increases the Index of Difficulty. In the second experiment, the different values of the frame rate do not have a significant impact on the users' performance - in this case the number of failures during the experiment. Another interesting result was found after the analysis of the Simulator Sickness questionnaire SSQ [16]. Users did not complain about cybersickness at all. Only the concentration after an experiment was worse than before the experiment. Some users stated a slight exhaustion after the tests but there was no occurrence of nausea or dizziness.

3.2 Macroergonomic questions

In contrast to microergonomics, the term macroergonomics refers to complex systems with multiple relevant influencing factors. In a VE it would also relate to multi-factor effects. The most important ones are workload, presence, situational awareness, total human C4ISR system performance, and simulator sickness.

In our actual work we examine these effects for a VE-training system with different display technologies. Clear and brief, we wanted to see if the use of high-tech immersive VE allows better transfer of navigational knowledge than a low-tech CRT-display. Another aspect is the appearance of simulator sickness. It was postulated, that more immersive displays can cause a larger amount of nausea and disorientation than less immersive displays.

In the actual setting we used an immersive head-mounted display, a stereoscopic large-scale projection wall, which still allowed the perception of peripheral sight, and a standard 21” CRT with shutterglasses.

Subjects were instructed to localize landmarks in a synthetic town, memorize landmarks and their position, and report them after 12 minutes exposition with free navigation.

Analysis is still ongoing, so no final results can be presented. However, it was found that simulator sickness effects occurred only for a very small number of participants. Interestingly, it seems to occur with the same likelihood for each display. With regard to training transfer no final results can be presented at this point of time.

4 OUTLOOK

As seen from our results, our past research focus was on microergonomic topics and is moving towards macroergonomic topics. We need new metrics for assessing performance metrics to actually measure the benefit of the application of VE for display of C4ISR information.

But these studies only serve as a basis for determining more general advantages and disadvantages of AR and VE technologies as a tactical situation display. By relying on these findings, the displays can be optimized and applied as displays for a more comprehensive analysis of their effects on human decision making effectiveness. In this case, differences in situational awareness and human decision making performance using traditional media on the one hand and new, AR and VE media on the other hand, will be investigated. For instance, it has to be analyzed, if the goal of higher realism has a positive or negative effect on training effectiveness. One outcome of this analysis will be a more detailed recommendation of special AR or VE technology for special education and training sections.

But for making full use of the capabilities of the new technology, the displays have to be integrated into new C4ISR concepts like NCW or CROP have to be developed. They can acquire benefits from the high level of interaction, realism and intuitiveness of the presentation of the training scene. By incorporating, for instance, a continuous shift between a strategic overview and an individual, operational point-of-view, complex interrelationships and situational development can be displayed easier than with today’s media. This development, however, has to incorporate today’s findings about handling and applicability of AR and VE technology.

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