Effects of Stereoscopy on a Human-Computer Interface for Network Centric Operations

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Keywords: Stereoscopic Vision, Human Computer Interface, Network Centric Operations, Command and Control System.

Abstract: Network Centric Warfare can be accomplished thanks to a network of geographically distributed forces, granting a flow of increased contents, quality and timeliness of information, building up a shared situational awareness. When this flow is displayed to an operator, there is the possibility of reaching a state of information overload. To avoid this situation, new ways to conceive the interface between human and computer must be evaluated. This paper proposes an experimental stereoscopic 3D synthetic environment aimed to improve the understanding of the modern battle spaces. This facility is part of the LOKI Project, a Command and Control system for Electronic Warfare developed by Elettronica S.p.A. We discuss technical details of the system and describe a preliminary usability study. This first evaluation is very positive and encourages continuing research into Human-Computer Interaction for military applications.

1 INTRODUCTION

Network Centric Warfare (NCW) (U.S. Navy, 1995; Braulinger, 2005), and consequently Network Centric Operations (NCO), can be accomplished thanks to a network of geographically distributed forces. The network, directly connected to the platforms by means of sensing, commanding, controlling and engaging systems, increases contents, quality, and timeliness of information between nodes enhancing the *situational awareness*. In this context is more appropriate talking of shared situational awareness, because all the network elements can have access at the same up-to-date information.

Figure 1 shows an example of a Network Centric scenario: two different platforms (e.g., ships), have the capability of sensing some limited areas and each one has a personal limited awareness of its proximity (a); each platform sends collected data (e.g., electromagnetic tracks) (in (a) depicted as dotted arrows starting from ships) to a specific platform, known as Command and Control (C2), that has the special task to fuse data, in a manual or automatic way; then, the C2 sends the fused data (in (b) depicted as solid arrows starting from C2) to the platforms; in this way they will share the same enhanced situational awareness (b); this process is continuously repeated during the military operation.

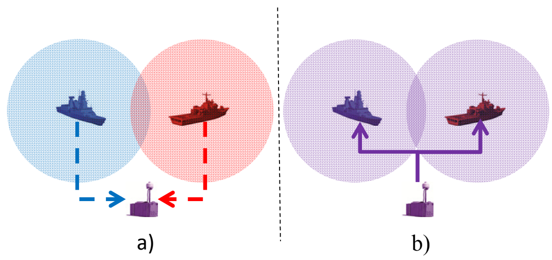

Figure 1: Example of a Network Centric scenario. In (a) each naval platform is collecting local data and send them to the C2 platform. In (b), C2 platform is sharing fused data with the naval platform, building up their shared situational awareness.

As described in the example, the C2 holds an important role in these networks; it is the system devoted to the decision-making process of the operational aspects of the warfare. Such systems are operated by commanders by means of a Human Computer Interface (HCI), in order to get access to information gained by the other platforms, that act like sensors in the network, and in order to make decisions (e.g., sharing the commander's perception

Zocco A., Cannone D. and Tommaso De Paolis L..
Effects of Stereoscopy on a Human-Computer Interface for Network Centric Operations.
DOI: 10.5220/0004850902490255
In *Proceedings of the 9th International Conference on Computer Vision Theory and Applications* (VISAPP-2014), pages 249-255
ISBN: 978-989-758-009-3

of the situation, manifesting command decisions) (Alberts, Garstka and Stein, 1999).

Increasing the number of commanded platforms, an operator of the C2 can easily reach a state of *information overload*, where information flow rate is greater than the operator's processing rate; this situation could cause a wrong mental model of the mission scenario and, consequently, the making of wrong decisions that could lead to catastrophic situations (Shanker and Richtel, 2011).

Thus, the HCI becomes a key factor when developing the architecture of a C2.

The focus of this paper is on the display issues of a HCI and how it can be improved in order to reduce information overload and enhance the usability of information. In particular, we evaluate usability of an immersive synthetic environment in the understanding of a NCW scenario.

This research is part of the LOKI Project, a Command and Control (C2) system for Electronic Warfare (EW) developed by Elettronica S.p.A. (ELT). Despite this work focuses on warfare topic, we believe that any time-pressure system operated by a human (e.g., HCI for network Intrusion Detection System), for network operations can benefit from this research (Cox, Eick and He, 1996).

2 RELATED WORKS

Gaining a detailed understanding of the modern battle space is essential for the success of any military operation.

In these applications, the main function of a human-computer interface is to display the current situation and the relevant information and intentions to the operator (e.g., location of own forces, reconnoitered opponent troops and facilities, commands and order from the superiors, platforms' status); this information is generally displayed on scaled maps with regional properties of the mission area.

Several research groups have focused their activities on the design and development of new display paradigms and technologies for advanced information visualization.

Dragon (Julier, et al., 1999) has been one of the first research projects in formalizing requirements for systems with the need to visualize a huge amount of information on tactical maps for real-time applications. A real-time situational awareness virtual environment for battlefield visualization has been realized with an architecture composed of interaction devices, display platforms and information sources.

Other solutions have been proposed by Pettersson, Spak and Seipel (2004) and Alexander, Renkewitz and Conradi (2006). In the former, the proposed visualization environment is based on the projection of four independent stereoscopic image pairs at full resolution upon a custom designed optical screen. This system suffers from apparent crosstalk between stereo images pairs. The latter presents some examples of Augmented Reality and Virtual Reality technologies, showing benefits and flaws, and the results of the experiments regard the evaluation of visibility and interactivity performances.

Kapler and Wright (2005) have developed a novel visualization technique for displaying and tracking events, objects and activities within a combined temporal and geospatial display. The events are represented within an X, Y, T coordinate space, in which the X and Y plane shows flat geographic space and the T-axis represents time into the future and past. This technique is not adequate for an immersive 3D virtual environment because it uses an axis to describe the time evolution constrains the spatial representation on a flat surface; the altitude information, that is an important information in avionic scenarios, can't be displayed. However, it is remarkable that the splitting-up of geographical and logical information (e.g., health of a platform) can enhance the usability of the system.

3 STEREOSCOPIC VISION

The stereoscopic vision can improve the understanding of a modern battle space by providing the depth perception and enhancing the level of realism and the sense of presence.

Different technologies have been developed for generating 3D stereoscopic visualization. Some of these are related to entertainment such as cinema (Lipton, 2007) and video games (Mahoney, Oikonomou and Wilson, 2011), as well as to other serious/work-related applications such as medical interventions and telerobotics (Dey, et al., 2002; Livatino, et al., 2010).

Stereoscopic visualization, or simply stereo, can be active or passive (Cyganek and Siebert, 2009). In short, passive stereo is a solution where light is polarized differently for left and right eyes. The polarization can be obtained in various ways; the most known is the colour polarization, used in cinemas in the 1950s for the first time. Nowadays, the most used polarizations within virtual reality applications are the linear polarization or the circular one. The latter has more degrees of freedom than the former when the viewer moves the head in relation to the image, avoiding effects that may degrade the stereo perception.

Passive stereo only needs a pair of low-cost LCD projectors, a pair of light cardboard glasses, both with built-in polarization filters and a good reflecting screen that assures that the light beam isn't omnidirectional reflected, but straight back to the viewer.

The active stereo requires glasses synchronized with the projectors; so, the right and left lens are blackened out alternately at the same rate of the images projected on the screen for the left and right eyes. Active stereo is generally more expensive than passive one because the former has the requirement of a 120 Hz image frequency and the normal projectors are usually not built for this frequency.

The stereoscopic visualization artificially reproduces the mechanisms that govern the binocular vision and it is closer to the way we naturally see the world (Drascic, 1991).

The stereoscopy leads to several improvements: comprehension and appreciation of presented visual inputs, perception of structure in visually complex scenes, spatial localization, motion judgment, concentration on different depth planes and perception of material surfaces.

However, a stereo vision could be hard to get right at first attempt because the hardware could cause crosstalk, misalignment, image distortion (due to lens, displays or projectors), and all these situations can cause eye strain, a double image perception, depth distortion, look around distortion (typical for head-tracked displays). These drawbacks prevented a large application of stereoscopic visualization (Sexton and Surman, 1999).

4 PROPOSED INVESTIGATION

The main goal of the research presented in this paper is the design and implementation of a visualization system for NCW scenarios (e.g., displaying symbols and logical information on tactical maps) by creating a stereoscopic 3D synthetic environment aimed at a total immersion of the operator. This facility is part of the LOKI Project, a C2 system for Electronic Warfare.

4.1 High-level Architecture of LOKI

Figure 2 shows the high-level architectural view of the LOKI system.

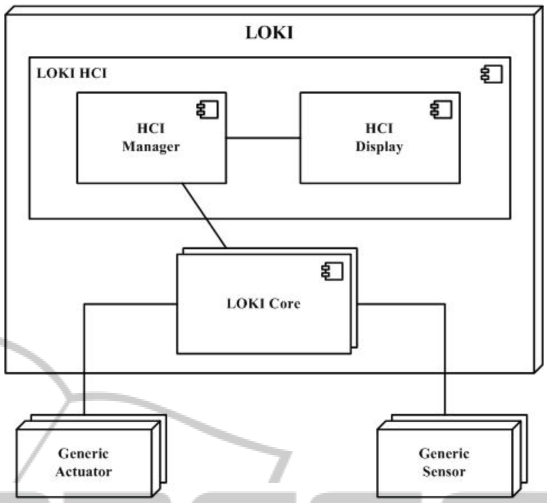

Figure 2: LOKI architecture in the large.

The *LOKI Core* component continuously executes an advanced multi-sensor data fusion process on the data retrieved from cooperating systems. Once these data are properly fused, the system is capable to infer new important information such as a better localization of emitters and countermeasures strategy. This information is transferred to the *LOKI HCI* using a communication middleware based on Data Distribution Service (DDS) paradigm (OMG, 2007).

The *HCI Manager* component provides a persistence mechanism to decouple the presentation layer from the core application logic. It is responsible for the communication with the core (i.e., receiving input data by the core and sending operator commands to the core) and for the translation of received data in a model understandable by the presentation layer.

The *HCI Display* component contains the elements that implement and display the User Interface (UI) and manage user interaction. It provides a high definition view of a realistic geographic environment. Platforms are positioned on the scene according to their geographic coordinates and are represented according to the Common Warfighting Symbology MIL-STD-2525C standard (Department of Defense, 2008).

4.2 Design Choices for HCI

The HCI has been designated with high modularity applying UI Design Patterns (UIDP). Using these patterns helps to ensure that key human factors concepts are quickly and correctly implemented within the code of advanced visual user interfaces (Feng, Liu and Wan, 2006). In addition, structural patterns Composite and Decorator were used: the former allows to dynamically add properties (e.g., borders around a window) or behaviors (e.g., scrolling) to any component of the interface; the latter allows to compose interfaces as tree structures, to show part-whole structures, and lets to equally handle single objects and compositions (Gamma, et al., 2005).

The software has been developed in Java language~~,~~ using an OpenGL binding in order to talk to the OpenGL runtime installed on the underlying operating system.

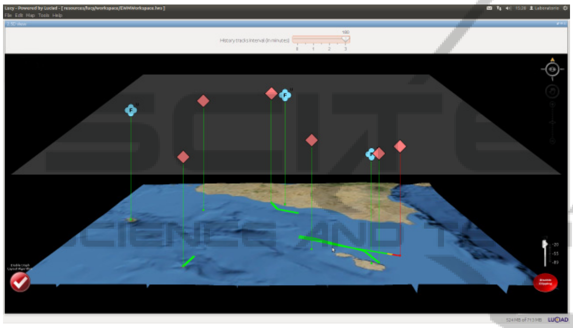

Figure 3: Visualization of EW entities with their geographic location.

Figure 3 shows a sample of the interface, built up in two different layers, as inspired by the research of Kapler and Wright (2005). A 3D terrain map, in the bottom part of the screen, is used to show both features of the selected terrain and geographic data of the elements of the scenario (e.g., real position, past track) and for elements that are not grounded, a transparent curtain is used to indicate their altitude. A parallel layer, that hosts the so-called “logical view” of the scenario, displayed above is used to represent other relevant non-geographic information (e.g., health status, lethality); it can be also used to visualize connections between the elements and to show elements that are outside the area that the operator is currently viewing in the geographic layer below. The geographical reference is maintained through connections between the two layers, using an algorithm of forces that avoids most possible crossing between lines. This separation, with the use of colours to show different levels of alerts, grants the operator the possibility to focus on geographic locations avoiding the overloading of symbols and text on the terrain.

4.3 Hardware Setup

The stereo vision setup includes:

- a PC equipped with a Nvidia Quadro graphics card;
- a Digital Light Processing (DLP) projector with a WUXGA (1920x1200px) resolution and a brightness of 7000 ANSI lumens;
- a special eyewear comprising two infrared controlled Liquid Crystal Display (LCD) light shutters working in synchronization with the projector (Figure 4).

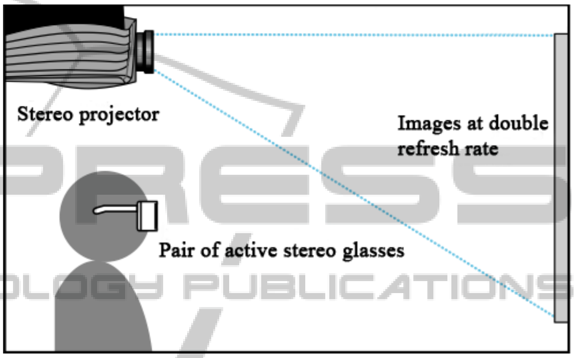

Figure 4: Active 3D display system.

When the projector displays the left eye image, the right eye shutter of the active stereo eyewear is closed, and vice versa. The projector is capable of displaying at a refresh rate high enough (greater than 120 Hz) in order that the viewer does not perceive a flicker between alternate frames. We decided to choose an active stereo system because more light is projected to each eye and therefore the 3D image appears brighter. We adjusted stereo parameters (i.e., separation and convergence) in order to obtain a negative screen parallax. So, when stereo pair is viewed through shutter glasses, the 3D objects of the scene appear out of the screen (Figure 5).

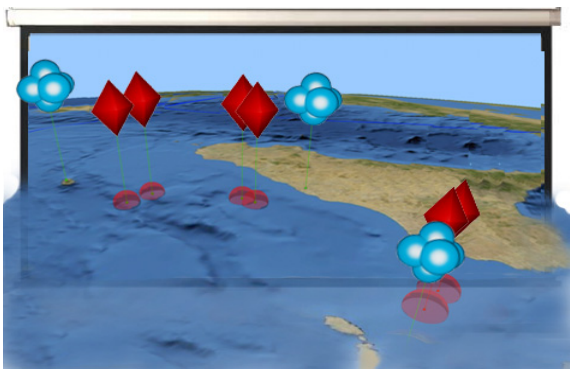

Figure 5: Binocular fusion of the stereo pairs.

4.4 Evaluation Setup

The preliminary evaluation study took place at the facilities of ELT in Rome and involved 12 users. The case study required around half hour per participant to be completed.

To evaluate the proposal, we developed a realistic scenario based on a coastal sea surveillance task. The user supervises, using both mono and stereo visualization, a relatively big area of sea, the Strait of Sicily, where there is a large volume of traffic, generated by different types of vessels. The operator is able to see the trajectory generated by each track and intelligence regarding each vessel.

The simulator, where the scenario is developed and executed, is an integration with Commercial-Off-The-Shelf (COTS) products and proprietary software and is based on the principles of distributed and live simulation (Sindico, et al., 2012).

The following qualitative data were collected using questionnaires and interviews: the realism of the visual feedback, the sense of presence, the depth impression and the user's viewing comfort.

4.5 Results

Most of the participants had no doubts that the depth impression (see Figure 6) and the sense of presence (see Figure 7) are higher in case stereo visualization. With complex electronic warfare scenarios, when monocular depth cues are ambiguous, the stereo viewing enhances spatial judgments: it is possible to detect very closely spaced icons on the screen (representing platforms with installed active emitters).

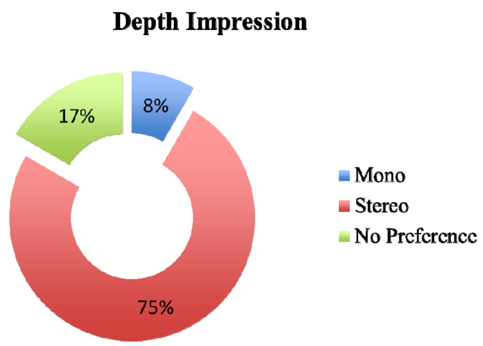

Figure 6: Preferences about depth impression by participants of the preliminary evaluation study.

All users find that stereo visualization provides more realism than mono-viewing (see Figure 8). The image resulting from the fusion of the stereoscopic pair is very clear and natural looking because

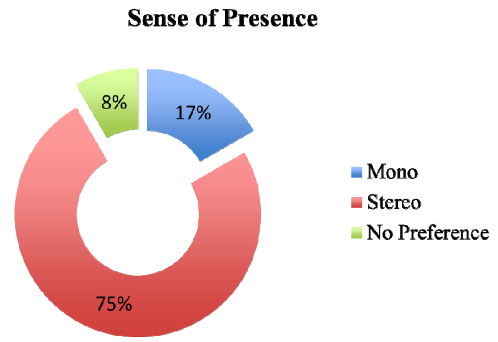

Figure 7: Preferences about sense of presence by participants of the preliminary evaluation study.

surface properties such as luster, scintillation, and sheen are different in luminance and colour between the left and right retinal images. This allows the viewer to perceive the differences between successive frames (e.g., platforms' positions) at a glance.

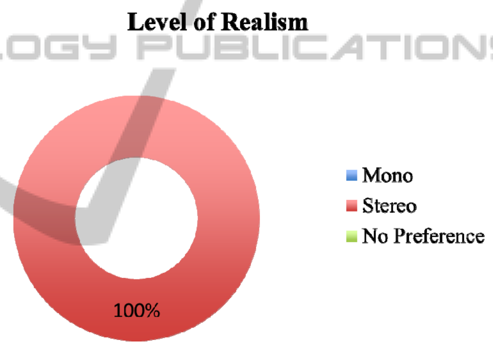

Figure 8: Preferences about level of realism by participants of the preliminary evaluation study.

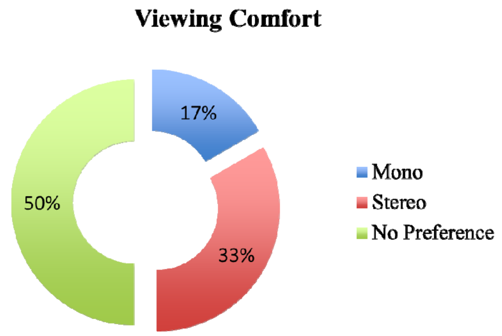

Figure 9: Preferences about viewing comfort by participants of the preliminary evaluation study.

There is no significant difference in viewing comfort between stereo and mono visualization (see Figure 9). This result, obtained through a reduction of the amount of parallax within each stereo pair, contradicts the general assumption of stereo viewing causes some problems such as visual fatigue and headache.

5 CONCLUSIONS AND FUTURE WORK

In the design and development of the C2 systems for NCO, a key element is the HCI. Bad assumptions may lead to bad design choices; those in turn may lead the operator to an information overload state. To avoid this situation, new ways to conceive HCI must be explored.

In this paper we evaluated the use of a stereoscopic 3D synthetic environment, aiming at a total immersion of the operator.

Preliminary evaluation shows the relevant role played by stereo visualization and its advantages in terms of sense of depth, presence and realistic viewing perception. The results presented are not authoritative in terms of metrics; however, they represent the initial experimentation phase of continuing research into user interface measurement for military purposes.

The lack of comparative evaluation with respect to other works specifically addressing NCW is due to the actual complexity of this domain. Livatino et al. (2010) obtained similar results in mobile robot teleguide based on video images. Even if applicative domains are different, similar results confirmed that we are in the right direction and more investigation must be done into HCI for military applications.

In the next future, we are interested in performing a formal user study aimed at improving and extending previous evaluations. We have designed a test plan according to recommendation gathered from the literature.

The test procedure will start with a brief presentation of the project and the purpose of the evaluation study. Then a visual attention test will be performed to classify the participants' level of selective visual attention. Each user will be involved in the understanding of a complex NCW scenario within an interactive test, during which quantitative data (e.g. errors made while estimating the distance, number and percentage of tasks completed correctly) will be recorded. The last step consists in the completion of pre-designed questionnaires to acquire qualitative data referring to the users' experience with stereovision technology.

We will evaluate the viewing comfort by subjecting participants to an intensive use of the system (about 3 hours). We will put special attention on the counterbalancing of the tasks as well as the sequence during the entire user study to avoid fatigue and learning effects. This aim will require the participants to perform the tests according to a precise schedule.

The collected evaluation measures will be analyzed through inferential and descriptive statistics and the results will be graphically represented by means of diagrams.

We expect that formal test results will clearly confirm the benefits of the stereoscopic vision in the understanding of a NCW scenario.

ACKNOWLEDGEMENTS

We would like to thank the colleague Andrea Sindico, who has supported us on the integration with this research and the LOKI project.

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