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C2VE: A Software Platform for Evaluating the Use of 3D Vision Technology for C2 Operations

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ABSTRACT

We present a software platform for analyzing different information visualization options in a command and control (C2) application. The key feature of this software is its ability to display information in 3D. For example, users looking at a map with our application can perceive the height and depth of the terrain. There are several C2 scenarios where 3D information could be helpful, such as determining if the terrain is too steep for passage or ascertaining line-of-sight information for reconnaissance. However, in general applications, there are mixed results about whether or not displaying information in 3D is helpful to the user. Specifically for C2 systems, the impacts of 3D visualization are not well-studied, so our software can help researchers determine if and how 3D displays can be most effectively used. For comparison purposes, the software can display information on a standard computer monitor (i.e., 2.5D display) or on one of two different 3D display devices. The information displayed includes terrain with satellite imagery, user-drawn areas of interest, 3D outlines of building exteriors, and standard military symbols from MIL-STD-2525C (with some annotations). These symbols can be displayed in three different formats (billboards, terrain draping, or cubes).

1. INTRODUCTION

A command and control (C2) center receives a mixture of data types from various sources. In order to share the information among operators and to provide a collaborative working environment, C2 centers commonly display multiple windows across several large screens using a large projection system. While the screens are 2-dimensional, some of the heterogeneous data is naturally 3-dimensional. Specifically, the locations of military units, points of interest, and even the terrain of the battlefield[1] itself is naturally 3D data. This presents a challenge when trying to effectively

[1] For concreteness, we describe our system in the context of visualizing a battlefield. However, it is not limited to military applications. It is equally applicable to other C2 applications that involve visualizing units or points of interest in some geographic area (e.g., disaster response, border control, etc.).

present that data on a flat, 2D display space. One method of displaying 3D information with a 2D display device is to project the 3D information into the 2D plane. This is called a 2.5D display (e.g., Figure 1). However, 2.5D displays generate difficulties when the user needs to perceive the depth of things (e.g., Figure 2).

In contrast, a 3D vision system renders the data in a true 3D space, so that a user actually perceives objects in three dimensions by using stereoscopic vision. We anticipate that the utilization of this modern technology will help the user understand the information more intuitively by perceiving the depth accurately. While this seems like it would be particularly important for geospatial data like battlefield locations, the strengths and weaknesses of 3D visualization for C2 systems have not been systematically studied to our knowledge. Thus, one goal of the software we have developed is to facilitate studies into the effectiveness of different visualization techniques for C2 systems.

2. Background and Motivation

3D vision technology has been used in a variety of areas—such as simulation, scientific visualization, medicine, defense-related projects, and entertainment—to investigate 3D data from immersive virtual environments (Chittaro, Ranon, & Ieronutti, 2006; Yang, McMullen, Schwartz-Bloom, & Brady, 2009; Schwartz & Fleming, 2005). Despite many advantages of using 3D vision technology, it has a known issue related to depth perception. Unlike the real world, which has a variety of natural cues we utilize to accurately perceive depth, accurate depth perception in a computer generated 3D scene is not a trivial matter. Many researchers have studied this problem, trying to improve the user's ability to accurately perceive depth in a 3D virtual environment. Previous studies produced mixed results, showing a general trend of underestimation in depth perception in the 3D environment (Jones, Swan II, Singh, Kolstad, & Ellis, 2008; Grechkin, Nguyen, Plumert, Cremer, & Kearney, 2010; Wartell, Hodges, & Ribarsky, 2002). However, another study showed 3D visualization to be helpful for egocentric distance estimation during robot teleoperation (Livatino & Privitera, 2006).

Our software incorporates visual cues to help the user accurately perceive depth (Section 3.1.4). There are a number of studies that presented the importance of such depth cues (and their interaction) for depth perception accuracy in computer generated scenes (Patterson, Winterbottom, & Pierce, 2006; Cipiloglu, Bulbul, & Capin, 2010; Livingston, Zhuming, Swan, & Smallman, 2009; Hubona, Wheeler, Shirah, & Brandt, 1999).

When compared with a standard 2D interface, 3D interfaces projected into 2D are sometimes beneficial (Sun, Ding, Hao, & Shi, 2009) and are sometimes detrimental (Cockburn & McKenzie, 2001) to the usability of the system (St. John, Cowen, Smallman, & Oonk, 2001). *While we expect that 3D visualization will be helpful for a C2 system, the existing mixed results on 3D and 2.5D interfaces underscore the importance of systematically studying the strengths and weaknesses of 3D and 2.5D displays for C2 systems.* Our software is designed to facilitate such studies.

One particular comparison of interest is between a 3D display and a 2.5D display. Both 2.5D and 3D displays let the user zoom in close to the ground to get some sense of being on location, and the user can also zoom out and get a bird's-eye view of the overall situation. However, the 3D display has the potential to provide the user with a better sense of distance than the 2.5D display, since there is the added sense of depth with the stereoscopic vision from the 3D system (Livatino & Privitera, 2006). This could be helpful for determining steepness of terrain (which can render certain areas impassable) or line of sight (to help determine patrol routes or observation posts). Our software is designed to help researchers determine if these benefits do, in fact, exist, and what impact they have on the usability of the C2 system.

While the 3D versus 2.5D comparison is the primary motivation for developing our software, it supports other visualization comparisons as well. For instance, each military symbol has several optional annotations specified in MIL-STD-2525C. Our software allows inclusion or exclusion of these annotations, supporting research into what level of annotation is best. In addition, there are different options for taking the 2D symbols from MIL-STD-2525C and rendering them in a 2.5D or 3D display. As detailed in the next section, our software supports using these different options, which enables research into their strengths and weaknesses.

3. System Description

The key feature of our software is its ability to display information in 3D. This lets users who are looking at a map perceive the height and depth of the terrain. The remainder of this section provides details about our software and some hardware configurations that are supported by our software.

3.1. Software

We call our software C2 in a Virtual Environment (C2VE). It generates a simulated virtual battlefield with the following three major modules: 3D terrain module, symbol drawing module, and interaction module. The 3D terrain module combines a satellite image with an associated height map to display the terrain of a battlefield (Figure 1). The symbol drawing module lets users place and manipulate military symbols that can be displayed in three different formats. This module also supports other drawing methods that may be used as part of the C2 operations. The interaction module interfaces the operator and system to intuitively execute C2 related actions in the virtual environment. The following subsections describe each module in detail, after a brief discussion of the graphics engine used throughout the system.

3.1.1. OGRE 3D Graphics Engine

The C2VE system utilizes an open source 3D graphics engine called Object-oriented Graphics Rendering Engine (OGRE) for rendering the simulated 3D virtual battlefield. OGRE is a framework that provides a simple object-oriented interface for rendering real-time 3D graphics by taking advantage of graphics hardware to speed up the rendering process. The framework provides scene graph implementation, a robust resource management system, terrain components, 3D model loading, animation, and various other tools. The terrain component enables the generation of terrains based on elevation data sources such as height maps. It also provides extensive support for texturing. In addition, OGRE provides tools for loading custom 3D models and supports the drawing of custom objects through manual definition. By utilizing the OGRE framework, the C2VE system is capable of presenting a high quality 3D virtual battlefield on a large projection system in real time.

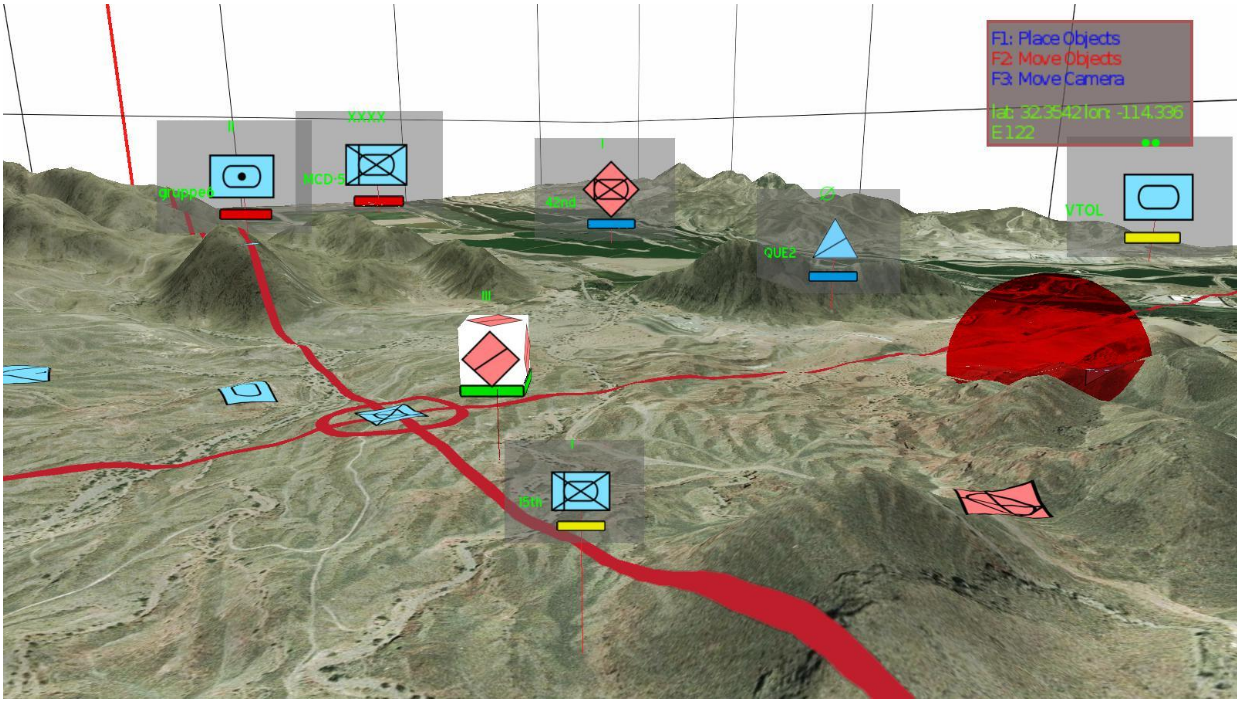

FIGURE 1: SCREEN SHOT OF C2VE

3.1.2. 3D TERRAIN MODULE

When looking at a geographic region in the C2VE system, the user can immediately get a sense of the terrain and major landmarks in a region because the system constructs a 3D virtual battlefield that combines elevation information with aerial imagery (Figure 1). One of the primary features of C2VE is the sense of depth that the user experiences when using the 3D system. Of course, this 3D experience cannot be adequately conveyed in a paper. However, Figure 2 highlights one case where a sense of depth is important to the user. From the given perspective, it is very difficult to tell from the screen shot (i.e., the 2.5D system) how far down the mountain one would need to go to get to the river. Of course, one could rotate the perspective in order to get a sense of that distance, but repeatedly altering the camera position (e.g., moving over across the river to look back at the mountain, then back to the original vantage point) could disorient the user. Instead, in the 3D system, the user gets a sense of how far away the river is without having to move the camera.

FIGURE 2: ILLUSTRATION OF 2.5 LIMITATIONS
Image Courtesy of Google Earth (© 2012 DigitalGlobe, Google)

We acquired several aerial orthophoto image files from the U.S. Geological Survey's Seamless Data Warehouse (U.S. Geological Survey, 2012). The image has the resolution of about 7000 by 7000 pixels and represents 7 by 7 km of the physical area. This is sufficient to give the user a good sense of buildings, rivers, roads, farms, trees, and mountains. The high resolution of the aerial image allows the terrain texture to maintain a high level of detail as the camera moves closer to the surface of the terrain.

The elevation data has also been retrieved from the USGS database in the Digital Terrain Elevation Data (DTED) format. The USGS provides access to the global digital elevation data that was originally collected by the National Aeronautics and Space Administration (NASA) as part of the Shuttle Radar Topography Mission (SRTM). The DTED data was then processed in MICRODEM mapping software to generate the height map image file that incorporates the elevation data of the target region (Guth, 2010). Specifically, a region of the planet that matches the aerial imagery has been selected, then exported as a grayscale height map image with resolution of 512 by 512 pixels.

The OGRE terrain system uses the resulting height map to generate the elevation for a terrain mesh model. The aerial image is texture mapped to the surface of the terrain mesh model through a bilinear interpolation. The generated terrain view displays a pictorial scene showing different levels of height. When the scene is rendered using the 3D vision technology, it presents a virtual space mimicking a real landscape view.

3.1.3. SYMBOL DRAWING MODULE

The C2VE system allows the user to interactively place and manipulate military symbols. The prototype system utilizes a subset of symbols from MIL-STD-2525C which are stored as textures. Because these are 2D symbols, there are several options for rendering them in the 3D battlefield view. C2VE supports the three different rendering methods described in MIL-STD-2525C: as a billboard, as a cube, or as a draped mesh (Department of Defense, 2008). Figure 3 illustrates a 3D terrain map showing the three different rendering methods.

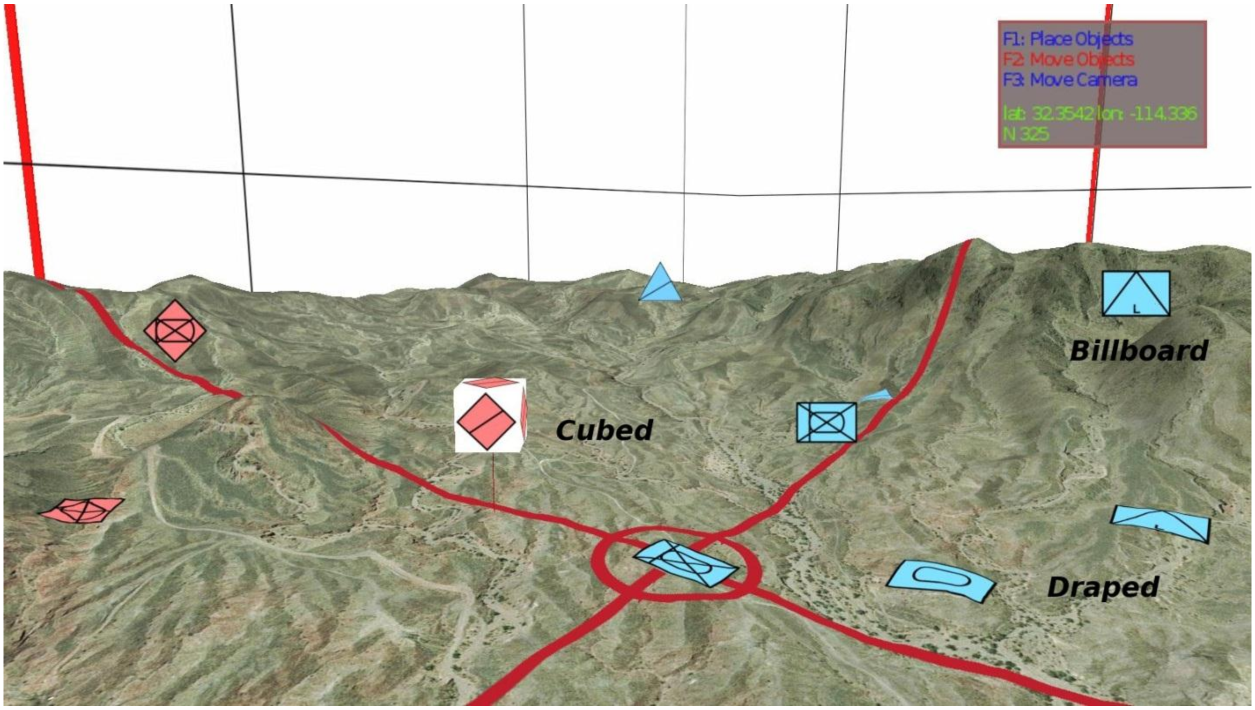

FIGURE 3: RENDERING SYMBOLS

The symbols in billboard format display as a square polygon with the symbol applied to the visible side. The cubed symbols have a 3D cube placed in the environment, where each face of the cube displays the 2D symbol. Both the billboard and the cube objects are placed on top of the terrain and dynamically change orientation according to the camera movement to ensure that the symbol is always facing the user. A symbol can also be rendered on top of the terrain as a draped object. The draped format generates a mesh that is located just above the terrain with the texture of the symbol applied to the visible (i.e., skyward-facing) side. This mesh object is fabricated based on the shape of the terrain that the mesh will be draped over. In this mode the symbol closely adheres to the terrain. Each time the draped symbol is moved, the mesh is reconstructed to adhere to the terrain shape at the new symbol location.

As seen in Figure 3, the C2VE software supports multiple symbol rendering types at the same time. This might be advantageous if different categories of symbols (e.g., mobile units versus geographically fixed symbols) are best rendered in different ways. Determining which rendering type is best in different situations is one question that our software could help answer as part of future research.

MIL-STD-2525C details several modifiers or annotations that can optionally be included with the basic symbols. These modifiers include both text and graphics (e.g., arrows) that can be added to the basic symbol. Our software supports several of these annotations (Figure 1), along with the ability to turn them on or off. That ability is included to help study what the best level of annotation is. While the annotations provide additional information to the user, if too many are included, they quickly clutter the visual space, leading to information overload. Thus, determining which annotations to include (and perhaps the context where they should be included) is an important question for C2 systems.

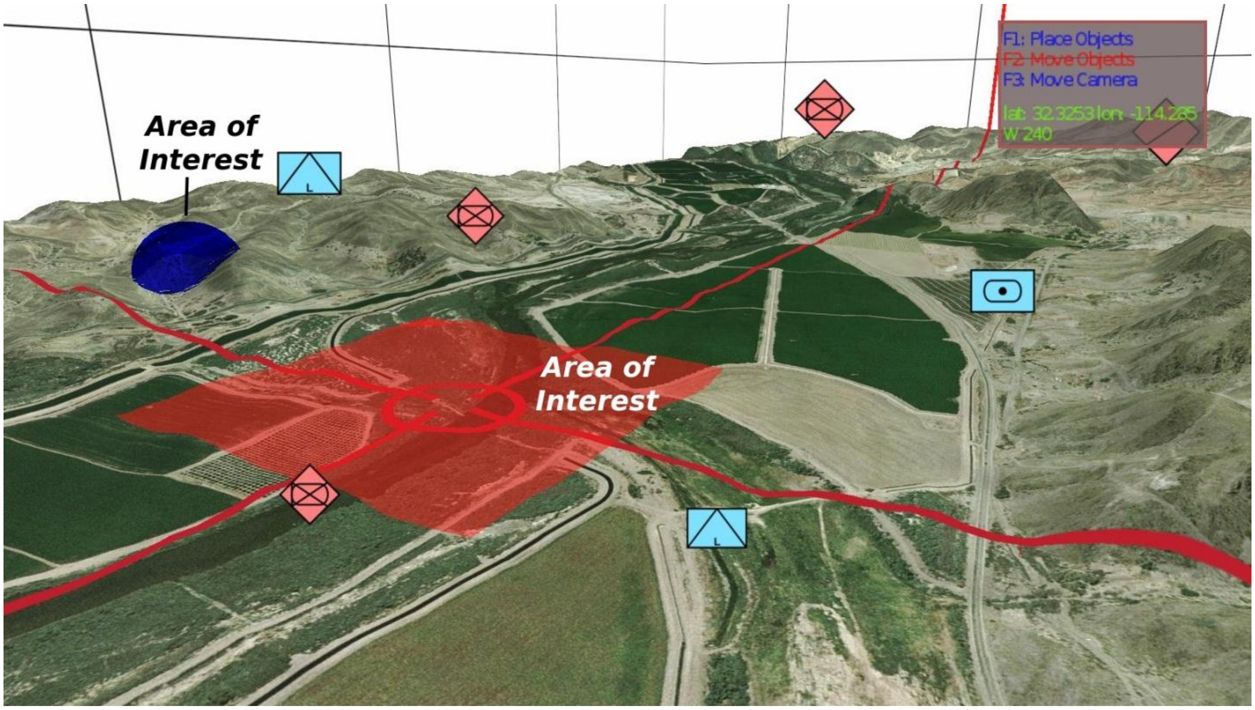

FIGURE 4: AREAS OF INTEREST

In addition to drawing the military symbols, our system also provides the ability for the user to designate areas of interest by drawing various geometric shapes on the terrain (Figure 4). These geometric shapes are commonly used to designate various areas such as battlefields, mine fields and training areas (Department of Defense, 2008). The C2VE software allows users to draw polylines, polygons, spheres, domes, and cubes. C2VE utilizes OGRE's ManualObject and built-in pre-fabricated meshes to draw these geometric shapes at the user's command. OGRE ManualObject is a class within the OGRE framework that allows programmers to draw objects by manually defining the 3D model. The user can manipulate the geometric objects including symbols and areas of interest by using 3D input devices (described in Section 3.2).

The OGRE framework also provides tools to load pre-modeled 3D objects into the virtual environment. The models can be constructed in an external 3D modeling program and then converted to OGRE mesh format, which allows them to be easily imported into the C2VE environment. Leveraging existing 3D models may provide a significant benefit to the system, as it is possible to tap into existing repositories of 3D models for buildings and military objects. The use of these models in the simulated battlefield can help the user discern relative sizes of the objects. Furthermore, incorporating 3D building models would provide important line-of-sight information, particularly in urban theaters.

3.1.4. *Interaction Module*

The C2VE system constructs an interactive virtual 3D environment. The user interacts with the environment via a 3D input device and a keyboard. The input device can be used to control either the cursor or the position of the camera. The keyboard lets the user toggle between these two modes.

In the cursor mode, the 3D input device lets the user move the cursor along the terrain. The cursor is used to place new symbols, delete or move existing symbols, and draw areas of interest in the battlefield. The location of the cursor is represented with the crosshairs projected on the terrain to help the user easily locate it in the environment (Figure 3). To further assist the user in locating the cursor, the virtual space is enclosed by a skybox that shows grid lines. Depending on the location of the cursor, intercept lines are rendered on the skybox that help the user to determine the cursor's current location. A previous study reported that properly used visual guidance cues minimize the depth ambiguity issue that can occur in navigating the 3D space (Cockburn & McKenzie, 2002).

The system also provides user with the ability to freely explore the environment by moving the camera and controlling the zoom level. The location of the camera can be controlled via the keyboard and other input devices such as a six degree-of-freedom 3D wand and 3D SpaceNavigator. These devices allow the user to manipulate and interact with the virtual environment in a straightforward manner. C2VE also allows the user to dynamically modify the size and orientation of the symbols according to user's preference. To facilitate user interaction, a menu-driven Graphics User Interface (GUI) has been developed. For placing a new symbol, the GUI organizes the possible symbols into related groups and allows the user to visually pick the desired symbol and the symbol visualization type (i.e., cubed, billboarded, or draped).

3.2. Hardware

We tested the C2VE software with three different 3D display technologies: two types of large 3D projection systems (e.g., for use in a command center) and a standard-size 3D-ready computer monitor (e.g., for greater mobility). For each of these configurations, the software ran on a desktop computer equipped with a six-core 3.33Ghz Intel Core i7 CPU, 12 GB RAM, and a NVIDIA Quadro 5000 graphics card.

The larger of the two 3D projection systems has a screen size of 160 inches wide by 90 inches tall (13.3 feet by 7.5 feet). Two HD projectors having 1920x1080 resolution generate two circularly polarized images on the rear-projection screen. Each projector displays the image for one of the user's eyes. The user wears passive polarized 3D glasses, which let the appropriate images through to the user's left and right eyes.

The other 3D projection system has 1280x1024 resolution, using a single projector and a front-projection screen. It requires active shutter 3D glasses, which quickly alternate which lens (left or right eye) is transparent. This is synchronized with the projector, which is quickly switching between displaying the image for the left eye and right eye. The left-right alternation happens quickly, so it is imperceptible to the user. We used NVIDIA 3D Vision glasses for our testing.

The third display option uses the same active shutter glasses, but instead of a projector, the system uses a 3D vision-ready computer monitor (1920x1080 resolution), which is about 22 inches across the diagonal. This small size makes it the most portable of the three display options.

FIGURE 5: TWO DIFFERENT 3D SPACE NAVIGATORS

For any of the display options, the user could interact with the system via a keyboard and a 3D input device. We used 3Dconnexion 3D SpaceNavigators (Figure 5) and 3D wands manufactured by Advanced Realtime Tracking (Figure 6) as our example 3D input devices.

FIGURE 6: 3D WAND

4. CONCLUSIONS AND FUTURE DIRECTIONS

The goal of our software is to facilitate future investigation into different visualization options for C2 systems. In particular, it can help researchers examine the strengths and weaknesses of 2.5D and 3D displays in C2 systems. Other visualization options that could be tested include different means of rendering standard 2D symbols in 3D, and different amounts or types of annotation for those symbols. We are preparing for usability tests in the coming fall to examine some of these questions, including an exploration of how depth perception in 3D C2 systems affects users' performance on their tasks. Such systematic studies will help inform the design and construction of effective C2 systems in the future.

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6. Bibliography

Chittaro, L., Ranon, R., & Ieronutti, L. (2006). Vu-flow: A visualization tool for analyzing navigation in virtual environments. *IEEE Transactions on Visualization and Computer Graphics, 12*(6), 1475-1485.

Cipiloglu, Z., Bulbul, A., & Capin, T. (2010). A framework for enhancing depth perception in computer graphics. *7th Symposium on Applied Perception in Graphics and Visualization*, (pp. 141-148).

Cockburn, A., & McKenzie, B. J. (2001). 3D or not 3D? Evaluating the effect of the third dimension in a document management system. *Conference on Human Factors in Computing Systems*, (pp. 434-441).

Cockburn, A., & McKenzie, B. J. (2002). Evaluating the effectiveness of spatial memory in 2D and 3D physical and virtual environments. *Conference on Human Factors in Computing Systems*, (pp. 203-210).

Department of Defense. (2008, November 17). *MIL-STD-2525C.* Retrieved March 2012, from http://www.mapsymbs.com/ms2525c.pdf

Grechkin, T. Y., Nguyen, T. D., Plumert, J. M., Cremer, J. F., & Kearney, J. K. (2010). How Does Presentation Method and Measurement Protocol Affect Distance Estimation in Real and Virtual Environments? *ACM Transactions on Applied Perception, 7*(4), Article No. 26.

Guth, P. (2010, April 23). *MICRODEM Home Page*. Retrieved March 2012, from http://www.usna.edu/Users/oceano/pguth/website/microdem/microdem.htm

Hubona, G. S., Wheeler, P. N., Shirah, G. W., & Brandt, M. (1999). The Relative Contributions of Stereo, Lighting, and Background Scenes in Promoting 3D Depth Visualization. *ACM Transactions on Computer-Human Interaction, 6*(3), 214-242.

Jones, J. A., Swan II, J. E., Singh, G., Kolstad, E., & Ellis, S. R. (2008). The Effects of Virtual Reality, Augmented Reality, and Motion Parallax on Egocentric Depth Perception. *5th symposium on Applied perception in graphics and visualization*, (pp. 9-14).

Livatino, S., & Privitera, F. (2006). 3D Visualization Technologies for Teleguided Robots. *ACM Symposium on Virtual Reality Software and Technology*, (pp. 240-243).

Livingston, M. A., Zhuming, A., Swan, J. E., & Smallman, H. S. (2009). Indoor vs. Outdoor Depth Perception of Mobile Augmented Reality. *IEEE Virtual Reality Conference*, (pp. 55-62).

Patterson, R., Winterbottom, M. D., & Pierce, B. J. (2006). Perceptual Issues in the Use of Head-Mounted Visual Displays. *Human Factors, 48*(3), 555-573.

Schwartz, R. J., & Fleming, G. A. (2005). Real-time aerodynamic flow and data visualization in an interactive virtual environment. *IEEE Instrumentation and Measurement Technology Conference*, *3*, pp. 2210-2215.

St. John, M., Cowen, M., Smallman, H., & Oonk, H. (2001). The use of 2D and 3D displays for shape understanding versus relative position tasks. *Human Factors, 43*(1), 79-98.

Sun, Y., Ding, N., Hao, G., & Shi, X. (2009). The Research and Application of 2D and 3D Interactive System. *Second International Conference on Information and Computing Science*, (pp. 252-254).

U.S. Geological Survey. (2012). Retrieved March 2012, from Seamless Data Warehouse: http://seamless.usgs.gov

Wartell, Z., Hodges, L. F., & Ribarsky, W. (2002). A Geometric Comparison of Algorithms for Fusion Control in Stereoscopic HTDs. *IEEE Transactions on Visualization and Computer Graphics, 8*(2), 129-143.

Yang, M., McMullen, D. P., Schwartz-Bloom, R. D., & Brady, R. (2009). Dive into alcohol: A biochemical immersive experience. *IEEE Virtual Reality Conference*, (pp. 281-282).