Guidelines for Use of Three-Dimensional (3-D) Graphics to Enhance Training of Explosive Ordnance Disposal (EOD) Render-Safe Procedures

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13. ABSTRACT *(Maximum 200 words)*
This report focuses on how 3-D graphical and interactive features of computer-based instruction can enhance learning and support human cognition during technical training of equipment procedures (where procedural training tasks are often highly specific to a piece of equipment). Studies of the effects of graphics, motion, and interactivity in technical training, and reports of successful instruction using state-of-the-art graphics and animation were reviewed to extract a set of guidelines for using 3-D interactive graphics to teach equipment procedures. The guidelines are directly applicable to the design of training of explosive ordnance disposal (EOD) render-safe procedures.

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Foreword

This research project was conducted under Program Element 0602233N (Education and Training), Work Unit RM33T29, Task 12 (Graphical Environments for Training Explosive Ordnance Disposal (GET-EOD)), and was sponsored by the Office of Naval Research. The research described in this report was conducted as part of a larger project to develop graphical methods to enhance the training for EOD personnel. The U.S. Navy is the lead department for EOD training within the Department of Defense.

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Summary

Background

EOD training does not generally utilize live ordnance for identification training, or for procedural training in rendering unexploded ordnance (UXO) safe. Instead, relatively realistic but inert exemplars of ordnance families are used in training. There are many problems with this approach. The EOD community needs a better means of providing realistic practice at affordable cost. One solution to this problem is to use an interactive, graphics-based system for training. A graphical environment with three-dimensional (3-D) visualization would allow personnel to safely learn the design of ordnance, as well as the best procedures to disarm the ordnance.

Objective

The objective of this project is to develop and evaluate a prototype graphical training system that effectively utilizes advanced interactive training techniques. New graphical technology exists to efficiently train procedural and conceptual skills without the need for the actual equipment. This graphical environment will allow EOD personnel to train whenever and wherever they want without risk to life and limb. However, in order to achieve effective utilization of graphical technology for EOD training, it will be necessary to integrate the requisite training strategies, instructional support features, and evaluation methods into the training system. The payoff will be the development of a generic system to train any task that requires ordnance identification and disassembly of a piece of ordnance.

The purpose of this research reported here is to outline guidelines for the design of instruction using 3-D interactive graphics to teach procedures. Procedural learning is a large category of learning and is one likely to benefit from inclusion of graphics in the instructional program. In technical training, the procedure to be trained often contains a series of steps to perform a task such as assembly of an object or operation of a control panel. Interactive 3-D graphics, in the context of simulation training, can very effectively display equipment, demonstrate a procedure, and provide opportunity for practice of the procedure, all in a highly visual manner.

Approach

This project is divided into three states. First, the training system requirements will be analyzed, and the specifications for the supporting graphical training technology will be developed. Second, a prototype graphics-based EOD training system with optimal training strategies, specific instructional features that match the capabilities of the hardware and software, and methods to assess training effectiveness with the graphical systems will be developed. Third, the prototype system will be evaluated and the specifications for the system will be revised. The purpose of this phase of the project is to develop the guidelines for the graphical features of the prototype EOD system.

Discussion and Recommendations

These guidelines are based on empirical research gleaned from primary and secondary sources, and others were derived from reports of successful instruction. Although the guidelines have a strong empirical basis, they should be viewed as tentative when applied to a new case of procedural instruction. They should function very well as hypotheses for the design, test, and evaluation of the new instructional material.

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Introduction

Problem

The U.S. Navy is the lead Department in the Department of Defense (DoD) for the training and support for Explosive Ordnance Disposal (EOD) personnel. EOD personnel must be able to correctly identify, and disarm or dispose of thousands of different pieces of ordnance. Many of the skills required on the job are only used intermittently, and it may be very expensive to practice on every item. Due to the need for EOD personnel to work safely and independently, EOD tasks are believed to require extensive practice in a realistic environment for both initial learning and for skill maintenance.

EOD training does not generally utilize live ordnance for identification training, or for procedural training in rendering unexploded ordnance (UXO) safe. Instead, relatively realistic but inert exemplars of ordnance families are used in training. There are several problems with this approach. First, there may not be enough pieces of ordnance available for every student to practice individually. Second, ordnance items may not be designed for routine disassembly, and may actually be destroyed or damaged during training. Third, the use of exemplars means the EOD personnel may not have had any practice with the ordnance pieces they have to render safe. The EOD community needs a better means of providing realistic practice at affordable cost.

One solution to this problem is to use an interactive, graphics-based system for training. A graphical environment with three-dimensional visualization would allow personnel to safely learn the design of ordnance, as well as the best procedures to disarm the ordnance. It would be possible to practice as often as necessary on any ordnance piece without concern for cost or availability. A graphical environment would also permit the exploration of job-related skills in ways that are not natural, and would be expected to result in a better mental model of EOD tasks. For example, objects could be disassembled and manipulated in exploded views independent of actual scale limitations. Although the procedural steps for an EOD situation can be delineated in text-based publications, it is believed to be necessary to practice EOD skills to develop automatic performance.

Interactive Graphics

Computer-generated graphics can now be integrated in real-time with audio, video, text, voice-recognition and speech generation in a two- or three-dimensional environment. This type of environment would provide interactive, intelligent training that would enable EOD students to practice more frequently, measure their increased performance capabilities, and develop a higher "survival" confidence level. This environment would provide the capability to teach the spatial characteristics of ordnance, and give a student the opportunity to encounter, resolve, and practice a method to render safe a specific piece of ordnance. Although an immersive environment may be preferable for this kind of training, the cost and the low spatial resolution of the hardware

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might require a non-immersive approach. In either case, a 3-D representation will probably be required for students to experience spatial relationships. Display technology will undoubtedly improve over the course of the research, and new innovations will be incorporated when appropriate as they occur.

The importance of a realistic environment for EOD training cannot be overemphasized. EOD personnel must correctly classify and identify any piece of ordnance, and they must memorize procedures to render this ordnance safe. Accurate CAD/CAM models of some pieces of ordnance already exist, and these can be incorporated relatively easily into a graphical training system. Animation of the disassembly of the 3-D models of the ordnance can be utilized to teach proper neutralization techniques. Previous research suggests that animated presentation of object assembly/disassembly procedures is as effective as actual practice on the object for retention.

EOD skills are believed to be highly perishable, and frequent practice is required to maintain requisite skill levels. Even if these skills were not very perishable, any error in performance could be fatal for EOD personnel. Perfect performance is the goal of EOD training. Since EOD tasks involve coordinated use of sensory, cognitive, psychomotor, and memory skills, the EOD training environment must be realistic enough in detail so that personnel can operate independently in the field. It is doubtful that simple viewing of object disassembly in the training system will be sufficient to ensure perfect performance. It is anticipated that training strategies and instructional support features, which support training in a graphical environment, will have to be implemented.

The use of graphics and animation in production of instructional materials is technically not a problem anymore (Yager, 1993). Because graphics packages make it very easy for users to produce and manipulate graphical images, we will be seeing many productions of educational software incorporating 3-D graphics, animation, and other sophisticated graphics techniques. Students will be able to visualize objects, manipulate images in real-time, and even create their own images for active participation in learning (Alesandrini, 1987). Swezey, Perez, and Allen (1991) have remarked that recent research has taken a new direction by examining specific attributes of various media, such as motion, which may enhance instructional effectiveness.

Future learning applications are likely to have graphical packaging, but it is not clear what will be gained in terms of instructional content. Computer-based graphical instruction, of course, will suit some types of learning better than others, but research comparing the effectiveness of various types of media has not produced solid conclusions about how learning variables relate to instructional variables. Reeves (1993) found that conclusions are impossible due to technical and methodological problems in the research. Reeves points out that several studies fail to provide sufficient information about the treatment to allow meaningful comparisons, and that most instructional treatments were too brief to be effective, most being less than 30 minutes long.

Visual processing is often the predominant learning mode in procedural tasks, such as assembly or operation of a control panel, that involve highly practiced motor skills

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applied to a new piece of equipment. The key objectives in these learning situations are (1) to understand the spatial structure of the equipment objects and (2) to learn a sequence of motor acts that relates to the physical layout of the equipment. Interactive 3-D graphics can satisfy these objectives by creating opportunities for visualization of equipment objects in new and exciting ways. Objects can be seen from several points of view. Complex objects can be presented in solid or wire frame. Object parts can be magnified for showing detail. Learners can see dissected views of an object or object transformations. And it is feasible to have all of these visualization opportunities under control of the viewer, if desired. Hopefully, such image manipulations will help the learner to form an accurate mental model of the physical components of the equipment, and possibly some of its physical functions as well (Bennett, 1992).

Three-dimensional animation provides the additional benefits of motion. Animation can be used to depict the structural and functional relationships among objects (Park & Gittelman, 1992) or it can be used to show a continuous sequence of actions and consequences of actions in procedural simulations (Wetzel, Radtke, & Stern, 1994) be compressed, or not to scale, to save on wait time or set up time (Leonard, 1992). In procedural simulations where training of manual skills is not an objective, animation of the procedure draws attention to the visual aspects of the procedure, such as the location of an action and the system response to it. Explosion, in which parts of objects are shown as moving outward to depict object disassembly and implosion, in which the object parts are shown as coming together to depict assembly, have been used very successfully in procedural learning tasks involving assembly or disassembly of an object (Wetzel, et al., 1994).

Instructional programs in which the learner is given the opportunity to interact with the program are often found to be more effective than those programs with little or no interactivity (Cronin & Cronin, 1992). Increased learner involvement can take many forms. In one case, a learner may be given the opportunity to explore a database in a manner totally under learner control. In another case, a learner may be involved in simulations involving complex interactions of the user and the computer, as in virtual reality simulations.

Interactive graphics refers to learner's interaction with images. Images can be enlarged, flipped, rotated, animated, duplicated, colored, sized up or down, moved around the screen, deleted, etc. The degree of interactivity is determined by how often the learner controls these various activities and how often the computer controls them. In the automated classroom, we can give control of these activities to the teacher. In the future, research and development of computer graphics is likely to focus on techniques for means of controlling and interacting with the visualization process that parallel the way in which images are mentally decomposed and manipulated.

Objective

The objective of this project is to develop and evaluate a prototype graphical training system that effectively utilizes advanced interactive training techniques. New graphical

technology exists to effectively train procedural and conceptual skills without the need for the actual equipment. This graphical environment will allow EOD personnel to train whenever and wherever they want without risk to live and limb. However, in order to achieve effective utilization of graphical technology for EOD training, it will be necessary to integrate the requisite training strategies, instructional support features, and evaluation methods into the training system. The payoff will be the development of a generic system to train any task that requires ordnance identification and disassembly of a piece of ordnance.

The objective of the current research is to outline guidelines for the design of instruction and to teach EOD render-safe procedures that uses 3-D interactive graphics. Procedural learning is a large category of learning and is one likely to benefit from inclusion of graphics in the instructional program. In technical training, the procedure to be trained often contains a series of steps to perform a task such as assembly of an object or operation of a control panel. Interactive 3-D graphics in the context of simulation training can very effectively display equipment, demonstrate a procedure, and provide opportunity for practice, all in a highly visual manner.

Approach

This project is divided into three stages. First, the training system requirements will be analyzed, and the specifications for the supporting graphical training technology will be developed. Second, a prototype graphics-based EOD training system with optimal training strategies, specific instructional features that match the capabilities of the hardware and software, and methods to assess training effectiveness with the graphical systems will be developed. Third, the prototype system will be evaluated and the specifications for the system will be revised.

The purpose of the first stage of the project is to develop the guidelines for the graphical features of the prototype EOD training system. The guidelines were developed by reviewing previous research studies of the effective use of graphics, video, and text in procedural instructions (Baggett, 1987 & 1989; Bieger & Glock, 1982; Nugent, 1988; Palmiter & Elkerton, 1993; Palmiter, Elkerston, & Baggett, 1991; Park & Gittelman, 1992; Wetzel, Radtke, & Stern, 1994), and the use of simulation as an instructional tool (Alessi, 1988; Bennet, 1992; Reigeluth & Schwartz, 1989; Thurman, 1993; Towne & Munro, 1992). There are also frequent references to the literature of cognitive imaging involving mental rotation of objects (Brown & Gallimore, 1995; Cooper & Shepard, 1984) and mental assembly of objects (Finke, 1990; Kosslyn, Reisser, Farah, & Fliegel, 1983). These guidelines tend to emphasize the importance of pictorials and motion to enhance visual learning of procedures.

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Guidelines

1. **Use 3-D graphics to represent equipment objects.**

   Three dimensional graphical illustrations of equipment fall into a category of graphics called representational graphics (Alesandrini, 1987). Computer-based representational graphics may include photographs that have been digitized by a scanner, line drawings, video, or 3-D illustrations. In all of these examples the pictures are isomorphic with the objects they represent. Although realism is an important characteristic of this type of graphic, the amount of realistic detail may vary.

   a. **Graphics and animation should be task relevant.**

      Graphics should be relevant to the instruction; otherwise they may distract learners and detract from learning (Alesandrini, 1987; Bennett, 1992).

      Use representational graphics to provide a concrete, physical perspective of object components and functions (Bennett, 1992).

      Use animation where its attributes are congruent with the learning task (Rieber, 1990). For example, rotation of the object and explosion effectively depict the composition of an object.

      Graphic detail to achieve realism should be determined by the specific learning task and learner characteristics (Alessi, 1988; Wetzel, et al., 1994).

   b. **Show objects in ways that enhance 3-D interpretation.**

      Give the viewer enough views of an object to be able to understand its 3-D shape, but don't confuse him by spinning or tumbling it too quickly (Blinn, 1990). Rotate the object at a comfortable rate, about equal to the viewer's rate of mental rotation (Cooper & Shepard, 1984).

      One can more easily see a 3-D shape by simultaneously having two views of the object, a 3-D view and a top-down or the xy plane (Blinn, 1990).

      Viewing rotations of objects can improve mental rotation of similar types of objects, but may not be as effective as for transfer to all objects (Zavotka, 1987).

      Show viewers the animated change from 3-D to 2-D to improve learners' interpretations of orthographic drawings (Zavotka, 1987).

      Present solid 3-D before wire frame 3-D when wire frame animation is desirable (Zavotka, 1987).

      When showing unusual oblique views of an object, use landmarks or graphic elements to establish viewer orientation (McConathy & Doyle, 1990).

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Interposition (overlapping objects) will aid in the interpretation of 3-D visual images (Brown & Gallimore, 1995).

a. Direct attention to important parts of the objects.

Create neutral backgrounds (Blinn, 1990; Wetzel, et al., 1994).

The figural portion of a stimulus should be perceived as solid and well-defined, and appear to be in front of the ground (Fleming, 1987).

If an image can be made legible at a distance of 10 feet from the monitor, its detail is about right (Blinn, 1990).

The total number of visual elements on the screen should not exceed 7-9 (Wetzel, et al., 1994). There are limits on the number of parts a person can maintain in a mental image at any one time (Finke, 1990).

How the learner "chunks" an image of an object may be based on the Gestalt principles of similarity, proximity, and continuity. Some parts are distinct because they are easier to "see" (Kosslyn, Reiser, Farah, & Fliegel, 1983). This characteristic of visual processing may contradict the temporal order of assembly instructions.

Keep an image of the completed assembly (or subassembly) on the screen when graphically demonstrating the step-by-step assembly procedure (Baggett, 1989).

Use long shots (at considerable distance from the subject) to establish location, show general spatial relationships, and display broad-scale movement (Wetzel, et al., 1994).

Use close shots to emphasize detail, show significant features, and reveal reactions (Wetzel, et al., 1994).

Use the central area of the screen for visual elements that are most important. Use "rule of thirds": Center of attention should be one third up from bottom, or down from top, or inward from side (Wetzel, et al., 1994).

Increase the color saturation of an object if you wish the viewer to concentrate on its external appearance more than its meaning (Wetzel, et al., 1994).

Create strong visual images by having the object move toward or away from the viewer rather than using lateral movement. Or use diagonal movement for the strongest dynamic impact (Wetzel, et al., 1994).

d. Use interactive graphics, with hints on viewing strategies, to help the learner conceptualized the spatial representation of the equipment.

Allow the student to have control over multiple views of an object and additional textual elaboration (McConathy & Doyle, 1990; Kinzie & Berdel, 1990; Bennett, 1992).

Provide hints to the learner on viewing strategies before and during the program (Kinzie & Berdel, 1990).

Give the student feedback on viewing strategies usage after he completes the program (Kinzie & Berdel, 1990).

2. Present procedures in ways that enhance visual learning by viewing.

Graphic presentations of procedures produce fast visual processing and faster, more accurate performance during training when compared to text (Palmiter & Elkerton, 1993; Nugent, 1988). Animated demonstrations, in particular, may reduce processing demands in short term memory because the demonstrations include several important functions. They immediately identify what objects are available, the orientation of actions becomes clearer, and there is an observable line between user input and system response (Palmiter, Elkerton, & Baggett, 1991; Rieber & Kini, 1991). However, there is sometimes poor long-term retention and transfer for learners receiving animated demonstrations of procedures. Animated demonstrations alone may lead to a mimicking of the behavior with a mental representation of the task based solely on a rote procedure (Palmiter, Elkerton, & Baggett, 1991; Reed, 1985).

a. In a procedural simulation, the fidelity of user actions and system feedback is more important than the realism of the display.

For training manual skills, include a realistic number of possible actions and a realistic mode of action when learners are required to perform the simulated procedure (Alessi, 1988).

Include a realistic mode of feedback and immediate feedback if appropriate when learners are required to perform the simulated procedure (Alessi, 1988).

Showing hands is unnecessary in the depiction of a procedure (Wetzel, et al., 1994).

Use motion rather than static or textual methods for procedure learning because it provides critical discrimination and continuity information (Wetzel, et al., 1994; Rieber, 1990).

Presentations of a procedure are better shown from the performer's perspective rather than an objective viewpoint (Wetzel, et al., 1994).

b. Direct attention to important parts of the procedure.

Focus on critical elements when conducting a demonstration (Reed, 1985; Wetzel, et al., 1994; Rieber, 1990).

Demonstrate the implications of common or critical error (Towne & Munro, 1992; Wetzel, et al., 1994).

Direct attention to parts of a visual sequence before it is shown (Wetzel, et al., 1994).

Make graphic feedback obvious so that students are able to perceive it (Park & Gittelman, 1992; Reed, 1985).

A slow rate of animation is better than fast rates to show procedures (Sollenberger & Milgram, 1993; Wetzel, et al., 1994).

Present assembly of an object as a succession of images of its parts (the parts representing meaningful units or subassemblies) with pauses in between each part (Finke, 1990; Baggett, 1987).

c. Use narration or text to enhance the graphic demonstration of procedures.

Graphics alone can demonstrate procedures as long as the views depict the necessary spatial, operational, and contextual information (Bieger & Glock, 1982), but the learning tends to be short-term (Palmiter & Elkerton, 1993).

Narration can aid graphic interpretation if the image alone contains insufficient information (Locatis, Charuhas, & Banvard, 1990; Nugent, 1988), but tends to be ignored otherwise (Palmiter & Elkerton, 1993).

Present visuals either simultaneously or approximately 7 seconds before narration to achieve maximum learning (Baggett, 1994; Mayer & Sims, 1994).

Optimal listening occurs at about 160 wpm, but can be increased to 200 wpm with no noticeable decline in comprehension (Locatis, et al., 1990).

Textual information should be added if the goal is long term retention and generalization to similar procedural tasks (Palmiter, Elkerton, & Baggett, 1991; Carpenter & Just, 1992).

Use textual elaboration to explain why certain actions were performed, what responses of the equipment should be noticed, and why those responses occurred (Towne & Munro, 1992).

Present animation frames in large segments, if interspersed with text, so that there is time for the viewer to attend to relevant details of the animation (Rieber, 1991).

On-screen instructions, such as text to direct the viewer to perform a step in a task, should be presented in their correct temporal order (Wetzel, et al., 1994).

No caption should be displayed for more than 6 seconds (Wetzel, et al., 1994).

No more than two lines of text should be displayed at one time and each line should contain no more than 32 characters, including punctuation (Wetzel, et al., 1994).

If the procedure involves branching, depict the steps using maps or flow charts, rather than lists (Phillips & Quinn, 1993).

d. Use interactivity with coaching to help students perceive relevant details.

Use program-control (rather than learner-control) to ensure optimal order and choice of instructional segments (McNeil & Nelson, 1991).

If students are allowed to vary the sequence of instruction, do this in conjunction with advisement (Bennett, 1992; Hannafin & Colomaio, 1987; Shyu & Brown, 1992).

Use prompts and feedback to help students attend to relevant details of the graphic simulation (Reed, 1985; Rieber, 1990).

Use audio or visual coaching, rather than text (Austin, 1994).

e. Include practice of the procedure in the instructional sequence.

Actual practice of a procedure has often been found to be better than simply watching the procedure (Wetzel, et al., 1994; Baggett, 1987; Kim & Young, 1991).

Actual practice of an assembly procedure is no better than having the learner imagine going through the procedure (Finke, 1990).

Use a variety of practice scenarios if a procedure must be generalized (Kim & Young, 1991; Reigeluth & Schwartz, 1989).

Make sure interactions with the instructional program do not interfere with actual practice of the procedure (Baggett, 1987).

Chunk a long procedural sequence, so that units are viewed separately with practice in between each unit (Baggett, 1987; Braby, Hamel, & Smode, 1982; Wetzel, et al., 1994).

Conclusions

Many of these guidelines are based on empirical research gleaned from primary and secondary sources, and others were derived from reports of successful instruction (Blinn, 1990; McConathy & Doyle, 1990). Although the guidelines have a strong empirical basis, they should be viewed as tentative when applied to a new case of procedural instruction. They should function very well as hypotheses for the design, test, and evaluation of new instructional material.

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