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MILITARY-BASED VIRTUAL SYSTEMS ENGINEERING

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ABSTRACT

This paper discusses how the military can and should move into the world of virtual systems engineering. In the past engineering designs were first done on paper, reviewed using scale models, and finalized in the full scale products. In the future all aspects of product design, manufacture, and repair will be done in virtual space. The ability to make changes "on-the-fly" and without "cutting metal" can save money and time, and will result in better designs. Online collaboration, rapid access to a broad range of tools and experts, and realization of the results into a format that can be quickly and easily understood will enable a decision maker to more fully understand the implications of a particular decision. These tools have broad application in both industrial and military decision making.

1 INTRODUCTION

Human computer interaction will significantly change military system engineering and technical decision making in the next ten years. Many leading companies already use some aspects of virtual reality and other human computer interfaces in their business. Personal digital assistants (PDAs), wireless communication, virtual interfaces, and many other technologies have the potential to provide a real-time interface to operational data, bringing a wide range of technical decision analysis tools to real-time situations. In this coming virtual world, simulation will be an essential tool. This virtual world will provide real-time interface for review of minute-to-minute operational parameters and enhanced decision control.

The key to this future is the development of "real-time" engineering algorithms. In nearly all circumstances an engineering answer now has much greater value than an answer a day, week, or a month from now. This is even more true in military applications. Many excellent engineering analysis techniques have been developed that are not routinely used as a fundamental part of engineering design, operations, control, and maintenance. This is because the time required to setup, compute, understand the result, and repeat the process until an adequate answer is obtained significantly exceeds the time available. This includes techniques such as computational fluid dynamics and finite elements, and optimization of complex systems. Instead these tools are often used in hindsight to understand what went wrong and how to improve the results next time. In the same way there are many tools for analyzing decisions after the fact but few real-time decision analysis tools.

This talk explores the components of a successful virtual engineering platform for the future military, presents the factors for successful implementation of virtual models, establishes realistic expectations for current technology, and helps the participant prepare for future innovations in modeling and simulation. Specific examples of Osprey visualization and battleground command and control are integrated into the talk to bring military relevance to the concepts presented.

2 VIRTUAL SYSTEMS ENGINEERING

Virtual reality is a confusing concept because it has been defined in many ways, and the term "virtual reality" has entered the popular culture. Virtual reality has been broadly defined by Carolina Cruz-Neira (1993) as "… immersive, interactive, multi-sensory, viewer-centered, three-dimensional computer generated environments and the combination of technologies required to build these environments." This describes virtual reality as discussed in this paper. It should be emphasized that the technologies referred to in the last phrase of this definition include all of the information technology and model development required to generate physically accurate simulations. The goal is to allow the user to experience the reality of the system by examining the computer generated system (scene) in the same way as the physical system, with the additional capability to make changes and rapidly see the impact of the changes. In this definition, virtual reality is not only the visualization delivery system (e.g., stereo projection, panoramic wall, head-mounted display, and surround projection) but also all of the capabilities required to generate a physically accurate visualization. This includes the application, the numerical model, the software coupling the numerical model to the visualization environment, as well as the visualization environment.

2.1 Key Technologies

Virtual reality is now accepted as an enabling technology that can be applied to a variety of scientific and engineering problems. Today's challenge is how to apply this technology to known problems in order to develop design approaches that will lead to better technical decisions at lower cost and in less time; that is, the development of *virtual systems engineering tools*. The ultimate goal of these tools is to provide a virtual engineering design space from the birth of the idea, through the design, engineering, manufacturing, operation or use, maintenance, and ultimately to disposal, recycle or reuse. We can imagine that a virtual design space that enables the designer, operator, manufacturing engineer, or any other individual the ability to experience the product just as if it were real. This will open a wide variety of activities which could be performed without ever building a physical prototype, e.g. testing design changes, revising material properties, and training. This is a very broad vision and realization of this vision will require significant advances in a number of areas. Table 1 provides an overview of some of the technologies that are required to design these virtual engineering workbenches.

Table 1 is not all inclusive and many of the areas overlap. Additionally, some of the areas are significantly more developed than others. Nonetheless, Table 1 provides a starting place for considering what is required to create virtual systems engineering tools.

- As shown, the traditional areas of virtual reality provide the basis for visualization and interaction.
- Physics based modeling, simulation, and analysis are key tools. Both the quality and the timeliness of the results are key issues. The continuing development of high fidelity models is required to ensure that physical processes can be accurately modeled. However, many models today require weeks or months to build and compute. Techniques are needed to allow these high fidelity models to be utilized within the design process.
- Engineering and design tools are needed to support real-time engineering design and human-in-the-loop design. In the current design process for many systems, the engineer steps out of the visualization environment after each iteration. In addition to real-time analysis and robust, interactive optimization tools, we need to develop an understanding of how to present the results such that the user can quickly relate them to their experience and understand how they impact the performance of the product.
- Human-computer interaction is an area of growing importance. The integration of a wide variety of devices into the engineering process provides the opportunity for true virtual engineering. An engineer in the plant could record a problem, transmit the findings to a large scale computer for analysis or to search a massive data set of recorded phenomenon, review the results, and contact a colleague to discuss the problem. All without leaving the plant.
- High performance computing is the backbone on which many of these applications run.

2.2 Background

Until the early 1990s synthetic environments were primarily based on head-mounted display technology and animations or fly throughs that were precomputed and precompiled (Bernard 1998). These provided non-interactive tours on pre-established paths through computer generated scenes. The growth of computing speed and memory enabled these computer generated scenes to be computed "on-the-fly" at rates sufficient for a video feed. This provided the opportunity for interactive walkthroughs. In these

Table 1: Key Technologies Needed for the Development of Virtual Systems Engineering Tools

Area	Virtual Environments	Physics modeling	Engineering and Design	Human-Computer Interaction	High Performance Computing
Technologies	Visualization within virtual environments	High fidelity models	Robust optimization tools	Haptics	Parallel computing
	Virtual collaboration	Multi-scale analysis	Physics driven interpolation	Portable devices	Massive data sets
	Multi-sensory reality	Coupled systems	Ways to see and understand the results	Remote collaboration	Computing grid
	Augmented reality	Real-time physics modeling	Real-time analysis tools	Wireless engineering	Long-lived data sets

walkthroughs the user defines the path and can examine the data/model at the speed and in manner that they choose. Also in 1992 and 1993 three new virtual reality systems were introduced, the Virtual Portal (Deering 1993), the CAVETM (Cruz-Neira et al. 1992), and the Responsive Workbench (Frölich et al. 1995). These systems provide a significantly different experience from the head-mounted display. The user experiences the model in a more natural interface, with a greater sense of presence and can share the virtual experience with other users.

From this point many software and hardware tools to support the use of virtual systems have been and are being developed. Current applications of virtual reality include architectural walkthroughs, virtual prototyping of mechanical systems, modeling of factory floor systems, education and training, and health and medicine. Specific engineering applications of virtual reality in car manufacturing include design reviews, styling, collision detection, and assembly/disassembly of parts (Mahoney 1995, Mahoney 1997, Gottschalk 1994, Ellis 1996). Other engineering applications include safety review and operator training for chemical processing plants, and construction and assembly of ships (Unbescheiden 1998). The focus of these projects is viewing the component or system in a three-dimensional environment, determining interferences, and reviewing assembly procedures. Generally in cases where analysis (e.g., finite element or computational fluid dynamics) is viewed in a virtual environment, the data is static and only the current case or perhaps a small catalog of cases is available for viewing. Users cannot makes changes within the virtual environment and see the results immediately.

3 MILITARY APPLICATIONS

Virtual systems engineering for military application provides the same types of benefits as within industrial applications. These include:

- Processes, equipment, and strategies can be developed, tested, and modified within a virtual engineering systems platform,
- Products can be tested within the environment and under the conditions that they will have to perform in the field,
- Analysts, developers, warriors, and decision makers can all understand the product, the tradeoffs, and technical challenges before committing to larger development and testing programs,
- During military operations the complete history, from initial concept and analysis to current performance will be available to decision makers for rapid review, and
- Rapid simulation and optimization will provide real-time advice on tactics and strategies.

It will be a significant technical challenge to bring these battlefield tools from a vision to reality. The key components requiring development today are:

- Believable high fidelity models that capture the nuance and detail needed for decision making,
- Rapid analysis and recalculation techniques based on physics that will enable the user to utilize the high fidelity models to make real-time decisions,
- Methodologies for coupling these components and systems together to create complete virtual systems.

4 SUMMARY

The potential rewards and capabilities of virtual engineering systems far exceeds the cost of overcoming the technical challenges faced in developing these systems. Today there are many computational, analysis, and system optimization tools. However, few of these are capable of providing real-time decision support in an environment that enables the user to quickly understand the risks and rewards of a particular decision. The next step in the development of these tools is focusing on methodologies that provide rapid analysis of high fidelity computational results and present these results in a virtual environment.

REFERENCES

Bernard, J. 1998. Engineering and IPT. In *Proceedings of the 2nd International Immersive Projection Technology Workshop*, Ames, IA.

Cruz-Neira C., Sandin, D., DeFanti, T., Kenyon, R., Hart, J. 1992. The CAVE audio visual experience automatic virtual environment. *Communications of the ACM* 35 (6):65-72.

Cruz-Neira. C., 1993. Virtual reality overview. *ACM SIGGRAPH '93 Course Notes: Applied Virtual Reality,* ACM SIGGRAPH '93 Conference, Anaheim, California.

Deering, M. 1993. Making virtual reality more real: experience with the virtual portal. In *Proceedings of Graphics Interface '93* 219-226.

Ellis, G., 1996. Digital clay: transforming automobile design. *IRIS Universe* 37:28-32.

Frölich, B., Krüger, W., Grunst, G., Wesche, G. 1995. The responsive workbench: a virtual working environment for physicians. *Computers in Biology and Medicine* 25:301-308.

Gottschalk, M. A. 1994. Engineering enters the virtual world: VR technology steps out of the arcade and into the engineering toolbox. *Design News* 49:23-24.

Mahoney, D. P. 1995. Driving VR. *Computer Graphics World* 18 (5):22-33.

Mahoney, D. P. 1997. VR drives Chrysler's new cars. *Computer Graphics World* 20 (7):61-62.

Unbescheiden, M., 1998. Evaluation of VR-Technology: Applications Using 3- and 5-sided CAVES. In *Proceedings of the 2nd International Immersive Projection Technology Workshop*, Ames, IA.

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