

Employing Augmentation in Virtual Environments for Maintenance Training

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ABSTRACT

The application of conventional training methods displays many disadvantages particularly for highly complex equipment. Significant improvements and cost reductions can be achieved by means of three-dimensional computer visualization and animation of technical scenarios.

This paper identifies with a list of common problems which will be improved in the Virtual Training environment. The main idea is to develop a general modeling methodology that can be utilized in a wide variety of scenarios, while minimizing the need for programming simulation source code. The different layers of information used to define a training scenario are then described in detail. Both the author's view and the trainee's view of the developed prototype are presented.

Finally, the paper concludes with a description of the goals of a most recent research project which will adapt these scenario structures for utilization in an Augmented Reality environment.

AUTHOR'S BIOGRAPHY

AXEL HINTZE graduated as a mathematician from the University of Magdeburg in 1976 and received his Ph.D. degree in 1981 in natural sciences (Mathematical Analysis) at the same university. He was project-manager in the Department of Development and Research of a mechanical engineering company for 15 years. His research fields were mathematical modeling and simulation of technical processes, animation and Virtual Reality for the mechanical engineering industry. In the Department Planning- and Visualization-Techniques of the FhG-IFF he is now responsible for the applied research in the field of Virtual Reality.

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PROBLEM STATEMENT

Within the last few years, technical equipment has become increasingly more complex. This has also required an increased level of expertise from both the operator and the maintenance staff.

Traditional training methods such as printed documentation and slide shows, are often not sufficient enough to convey the entire complexity of a machine's design and functions. Therefore, it is still common to train operators and maintenance staff utilizing a piece of real equipment. For this purpose, manufacturing companies even maintain specialized training centers that are equipped with a variety of training equipment. Although this traditional approach provides adequate training, there are some disadvantages that have become more apparent in recent years.

- **Increasing variety of products**

Within manufacturing, there is a trend toward customized products. It becomes increasingly difficult to have many kinds of products available for training purposes.

- **Concurrency of training system with actual system**

Often, products are permanently improved and modified. Thus, the equipment found in the training center becomes quickly outdated.

- **Training center is bound to a specific location**

With the globalization of the market, companies extend their business to the international market. Training centers, however, are still mostly located near the manufacturing location, which in turn increases travel expenses.

- **Experts are only available locally**

Although training centers provide excellent training facilities, not every possible failure can be foreseen and trained. Due to the fact that there is currently no adequate approach to convey this

expert knowledge to the customer's site, the expert often has to physically travel to the customer's location.

- **Increasing cost for equipment**

Products not only become more complex, but also more expensive and subject to damage. Frequently disassembling and assembling a machine also accelerates wear-out and increases costs due to depreciation. Facing an increased competition on the market, it becomes more important to limit these costs.

In co-operation with other industrial partners, the Fraunhofer IFF researches training environments that will reduce the need for training that utilizes real equipment by means of modern information technology. The central idea is to utilize a virtual reality-based simulation instead of the real equipment.

REQUIREMENTS FOR A CREDIBLE TRAINING SIMULATION

One of the most obvious requirements for a credible training simulation is a sophisticated visualization of the training object. There is a vast variety of graphical applications, mainly CAD programs, available that could be utilized to represent the training objects in an appropriate manner.

Working with a computer instead of working with the real training object is always a second hand experience. Entering numbers on a keyboard or interacting with a mouse pointer is quite different from pushing buttons or pulling levers on a real piece of equipment.

By means of Virtual Reality (VR), however, these limitations can be diminished. Shutter glasses or head-mounted displays allow the user to perceive a three-dimensional vision. Data gloves or other devices with a force feedback control remove the computer keyboard or mouse interface. Gradually, the users can be immersed in the scenario and feel like they are in a virtual world. Although, there is still a lot of research work being

conducted in this field, and VR solutions are often very expensive, it is already possible today to take advantage of these technologies. Some CAD applications already incorporate the capability of creating stereoscopic images and some of them even allow data gloves to be used.

From our point of view, however, there is another dimension in the development of training applications that significantly contributes to the credibility of a training simulation - fidelity. Whereas graphical representation and the utilization of VR devices define the physical interface - roughly defined - fidelity represents the logical interface to the Virtual Environment (VE). The fidelity of a computer simulation describes the extent to which the Virtual Environment correctly responds to the user's actions.

For example, a VE that simulates repairing faults in an aircraft cockpit must correctly simulate the logic of fault isolation strategies and must respond correctly when the maintenance trainee repairs or fails to repair the fault. While this seems obvious, there is still a question of the fidelity of that logic. A repair may require the technician to complete a number of steps as the repair is effected. A high-fidelity simulation will react at every step. A lower-fidelity one might not react until the final step is performed.

Although it seems desirable to develop a high fidelity simulation of the training object, this requires a considerable amount of data and effort in creating the simulation model. This part of developing a training simulation is currently not very well supported by any kind of CAD or VR application.

The majority of solutions available today are very specific to a certain application and handle only a well-defined scenario. Within our current research project, we are looking for a more generalized concept of modeling the properties of complex equipment. We are looking for a concept that can be easily reused to model a different scenario. An important objective of our research is to enable the instructor to be the author of the system without having a strong background in computer science. With regard to the amount and complexity of the information, this is a real challenge that will be discussed more in detail in the next section. A few related articles dealing with the design of virtual environments are listed in the reference section [1]-[5].

THE LAYERED ARCHITECTURE

An essential characteristic of the application we intend to develop is a considerable degree of interactivity. In contrast to many other training applications, which mainly contain fly-throughs and only a few user interactions, our work is focused on user interaction. The technical system must be modeled close to reality in order to attain realistic training conditions. This means, the model should react the same as the real equipment and should also respond to user actions in the same way. Of course, it is necessary to enable the users to perform all relevant actions in the synthetic environment, that they would have to perform in the real world.

In addition to the geometry of objects, a lot more information needs to be modeled. This refers, for example, to the hierarchy of objects and possible parenting relations, movement constraints, causalities, properties and actions as well as dynamic behavior of objects. Furthermore, components are required to support the trainees in self-evaluating their actions, and in carrying out the communication between trainee and instructor.

In general, the information needed to model the training environment can be divided into three levels as shown in Figure 1.

- **Geometry level**

This level includes all nodes of different types (**geometry, animation, trigger, level-of-detail switches...**) as they are common to the scenario structure of most VR-systems available. These entities provide the formal base for the implementation of a scenario in a runtime system. Information of this level will be imported from other systems, such as CAD applications, by appropriate converters. This level is normally unknown to engineers, instructors and pedagogues.

- **Object level**

Based on the information from the geometry level, the object level specifies the basic objects that can be utilized in the next level for the definition of training scenarios. Each **object** comprises a defined set of **properties**. The current values of all properties define the **status** of the scenario. We call the entity of all possible states of a scenario the scenario's **phase space**. Technically, it is the cross product of ranges of values of all object properties. A subset of the phase space is called a **criterion**. Typically, it will be defined by logical conditions.

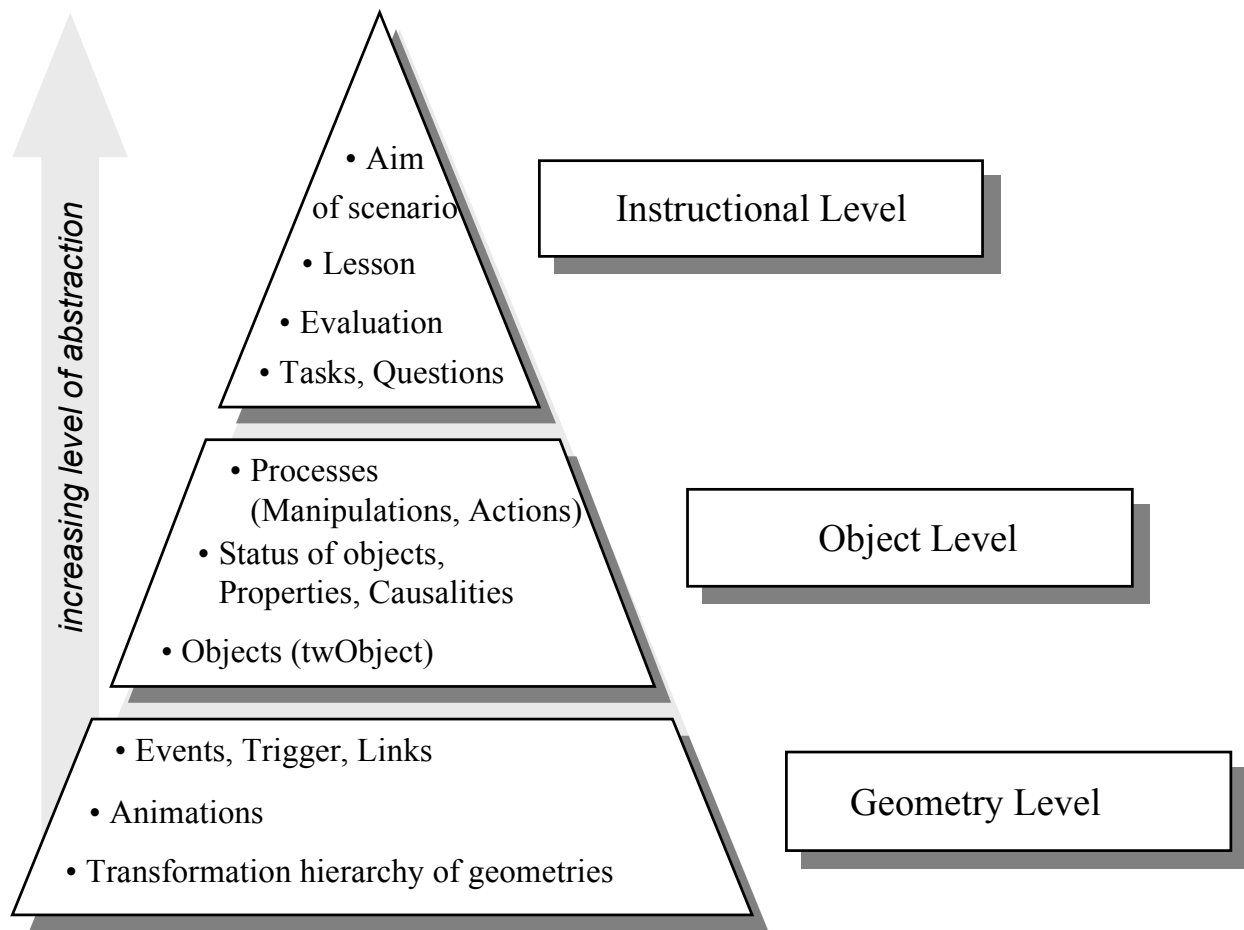


Figure 1: The different layers used to define a scenario

Based on these layers, it is now simple to define causalities between objects of all kinds. In common sense, a causality is a logical dependency between property values of certain objects. Within our methodology, a **causality** is comprised of a criterion and an action. The criterion is the prerequisite for the action to be performed. An **action** can be the assignment of property values, the start of an animation, waiting for a condition, or it can result in the invocation of other actions.

These layers can be utilized to model a wide variety of technical systems. At the same time, the need for writing programming code will be minimized or, in some cases, completely eliminated.

The object level contains all product-specific information that is already defined within the

design process. Additionally, it includes characteristics that are determined by natural constraints, e.g. gravity, collision detection to avoid inter-penetration of objects, etc.

This level is the domain of the design engineer. It contains the system-specific and technological know-how.

- **Instructional level**

Objects defined in the object level can be utilized here to form **training tasks**. Training tasks can be used to construct **lessons**. One or more lessons may be necessary to attain a certain **training objective**. This level is the domain of the pedagogue or instructor.

All three levels mentioned above depend on each other. Each level requires specialists from different areas.

From our point of view, it is important to emphasize the distinction between the levels of content (object level and pedagogue level) and level of the runtime system (geometry level). This distinction has been made in order to retain flexibility in terms of the runtime system and the hardware platform. Moreover, this separation allows the structures for representing content to be focused on the requirements of the specific field of application. Otherwise, one would be forced to adapt to the structures of the runtime system which have been developed on totally different premises and objectives.

Since the information that describes the scenario is processed before the application is running, this division does not affect the performance of the actual simulation.

In order to gain initial feed-back, we are in the process of developing scenarios for five industrial companies which intend to utilize our system. The current prototype already supports the functionality of the geometry and object level.

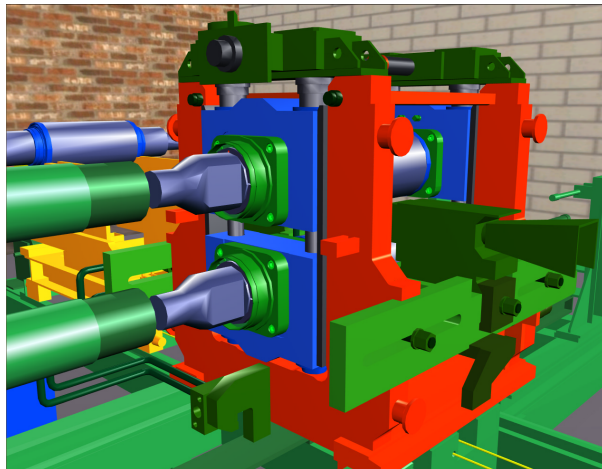


Figure 2: Rolling mill stand in maintenance device prepared for dismantling

This section introduced the general architecture of the scenario. The next two sections will discuss the two different views of the scenario. The author's view involves the functions that can be utilized to construct a training lesson. It also contains a description of the goals the learning process is aimed at. The user's view deals with the different presentation modes in which the knowledge is presented.

THE AUTHOR'S VIEW

A main focus of our research is aimed at the assurance of efficient communication between the experts of the different levels. For this purpose, we developed a system of lists with accompanying tools. Each list contains information to specific single aspects of the scenario (e.g. lists of objects, hierarchy, properties, processes, etc.) These lists can be generated from any working state. They can be made available in a human readable format. The author or another specialist can easily edit these lists and reload them into the scenario. Such a modified list replaces the former version, and therefore the scenario evolves in the process of editing.

The capability of modification and extension is integral in our concept. The reload of a modified list is combined with routines to examine consistency. If something occurs which leads to contradictions or uncertainties between the existing scenario and the additional information, a dialogue with the author is initiated. This method of external scenario generation allows simple data transfers, e.g. via e-mail, and requires only a simple ASCII-text-editor at the expert's site, which could be at a remote site of the author's location, to submit his knowledge-contribution. Independent of this it is possible to edit the same information online, in the same interactive graphical environment the trainee uses later on.

Our objective is to allow the person who has the knowledge to design the content of the training session to be the author. This person is not required to be a VR or computer expert.

The scenario structure defines the contents and structure of a training session. For the training system, the functions need to be defined which are necessary to carry out the interactions of the trainee within the scenario to reach the training objective. A choice of the basic functions is described below:

- saving and reloading of the current property values and degrees of freedom of objects caused by trainee-manipulation.
- ability to guided and free fly-throughs to demonstrate the structure of the technical system and to allow the choice of different viewpoints by the user.
- ability to save and reload defined viewpoints
- navigation in the scenario by object names and along the edges of the hierarchy tree

- access to object-related data by object name or picking
- step-by-step dismantling of the system to examine single objects in detail or to get access to interior components

The above mentioned basic functions are used to support the following steps of the learning process:

- **Knowing the structure of the system/plant**

The trainee navigates vertically and horizontally through the hierarchy of assemblies. The selected assembly is pointed out visually above the rest or displayed as a single object. It can be manipulated and viewed from all perspectives. Information, related to this assembly, is displayed in an additional window (e.g. name, description, substructure, properties, etc.). The application finds assemblies by name and displays them. Special views can be used (e.g. exploded view as illustrated in Figure 3). The system can ask questions (e.g. find a specific assembly or give the name to a highlighted assembly, etc.).

- **Knowing the functions of the technical system**

Complex functions are shown to the trainee as complete animation. Position and viewing direction can be chosen freely. Also pre-defined viewpoints are also available. To emphasize the items of interest, it is possible to use transparencies or different kinds of highlighting. The total process can be divided into sub-processes, which can be animated as often as desired. Information related to the sub-processes is available (e.g. name, explanation, relevant assemblies...)

- **Training of manipulative actions (maintenance, assembly, repair...)**

The system shows the manipulations in the correct order. Each step is accompanied by information concerning status changes of different assemblies and parts. The system can invite the trainees to perform certain steps on their own to achieve defined status changes. The system evaluates the user action and gives support if required. It is also possible to give only the desired status, and the trainees have to find the way on their own.

The trainees can act auto-didactically and define goals and achieve knowledge about interdependencies of the system by trial and error. They can attempt to perform a sequence of manipulations supported by the system with

information concerning missing status requirements of single assemblies or parts.

- **Training of diagnosis and repairs**

The instructor or the application generates a situation by hiding a fault in one substructure. The trainees have the task to find the fault and to repair it. Means for diagnosis can be visual and acoustic inspections, function examination or special diagnostic equipment. By dismantling assemblies they can approach faulty components and verify their diagnosis. If they find the faulty component, they can repair it, e.g. by setting the status of the component or by exchange with a working component, and after correct re-assembly the system will work.

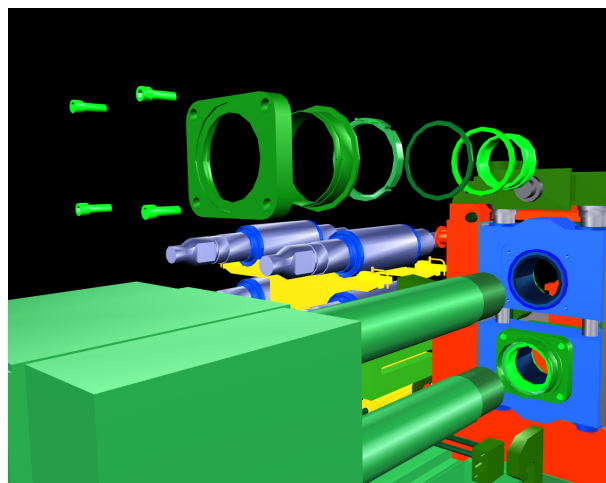


Figure 3: Bearing of top roller dismantled

THE TRAINEE'S VIEW

From the viewpoint of the trainee, there are three different modes that are supported:

- **Presentation mode**

The presentation is comparable to an interactive video where the users can determine the progress on their own. The viewers can branch to acquire more details on specific topics. Also they can chose different viewpoints.

- **Guided tour**

Using the knowledge acquired in the presentation mode, the guided tour defines concrete tasks that the trainee has to perform. The trainee will receive task-related hints and explanations. The order of sub-tasks is given by the system.

- **Free training**

In free training mode, the tasks become more complex and hints and explanations are only available on the user's request. If help is acquired, it will be documented each time and considered for the evaluation purposes of the training session.

Up to this point, the paper only discussed a virtual training environment. [6] [7] The next section will introduce an even more recent research project that will adopt the described scenario structure for the use in an augmented environment.

EMPLOYING AUGMENTATION

Whereas virtual environments already significantly enhance maintenance training, the users still have to deal with the large amount and variety of information they need to keep in mind when doing maintenance. By means of "Augmented Reality" this problem becomes manageable.

In a virtual world all objects are synthetic. This provides the difficulty that also all sensory feedback needs to be generated virtually. Specifically, the simulation of virtual sense of touch is still unsatisfying.

The idea of Augmented Reality follows a different approach. The trainee acts in the real world which is augmented with visual and audio augmentation elements. Visual augmentations are projected on See-Trough Glasses and overlay the real world's objects.

The main goal for using Augmented Reality is to provide On-the-job training. Not only can the system demonstrate how to accomplish a certain maintenance task but it can also assist the user with a variety of information, such as technical manuals or construction data. For example, if a part needs to be replaced during a maintenance procedure, the system could automatically come up with the appropriate catalog number or the system could even guide the technician to the right location in the warehouse where to find an replacement part.

Another application of Augmented Reality includes virtual transparency. By projecting a geometric representation of a device's inside on the projection glasses, the technician can see inside a machine and determine the position of parts without actually having to remove the cover parts.

In order to further explore the opportunities offered by Augmented Reality environments, we are

currently involved in a research project called STARMATE ("System using Augmented Reality for Maintenance, Assembly, Training, and Education") funded by the European Commission (IST program number 1999-10202).

The project is coordinated by Thomson-CSF Optronique, France and includes three research partners and three end-users.

Since the system is intended to assist a technician on the job, it is essential to limit any interference caused by the system's interface. Therefore, a voice recognition system will be used for command input.

The technician's position will be tracked by two cameras. This position information will then be utilized for the generation of the visual augmentation.

In addition to visual augmentation elements, audio augmentations can be employed to communicate spoken text or sound.

Basically, the same scenario structure - as described in the first part of this paper - can be applied. Only the method used to present the scenario's content to the end-user differs. Whereas in a virtual environment all scenario objects need to be visualized, only a selection of objects is visible in the augmented environment. However, the same scenario layers are still necessary to store the information.

Currently, the project is in an early stage. Therefore, no prototype of an Augmented Reality environment is available as of this writing.

CONCLUSION

Currently, there is a need to support maintenance training of complex equipment. A credible training simulation is not only comprised of a sophisticated visualization and an immersive user interface, but it also includes a high-fidelity representation of the real system. Instead of developing a solution that is specific to a certain end-user, this paper introduced a methodology that covers a wide variety of training applications. The modeling methodology also allows for the development of appropriate authoring systems that enable instructors of the scenario to develop training scenarios. Further research is currently underway to explore Augmented Reality environments.

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