VIRTUAL ENVIRONMENTS FOR THE TRAINING OF MAINTENANCE AND SERVICE TASKS

Eberhard Bluemel
Axel Hintze
Torsten Schulz
Marco Schumann
Stefan Stuering

Division Virtual Development and Training
Fraunhofer Institute for Factory
Operation and Automation
Sandtorstrasse 22
39106 Magdeburg, GERMANY

ABSTRACT

This paper presents an interactive, virtual reality based training environment specifically developed to support training of maintenance procedures of complex technical equipment. The architecture of the system will briefly be described. Moreover, the paper explains the different training modes that allow for adapting the training environment to the trainee's knowledge and determine the level of interactivity. A short glimpse is given to the scenario author's work. Finally, an example scenario will be described to demonstrate a practical application of the training environment.

1 CURRENT SITUATION

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. Whereas information technology has been successfully applied in the field of teaching theory, there are only a few applications in the field of practical training.

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.

- *Shortening of time interval for applying modifications:* Often, products are constantly 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 Thus, the equipment found in the training center becomes quickly outdated.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 marketplace. 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 damageable. Frequently taking apart and putting back together a machine also accelerates wear and increases costs due to depreciation. Facing an increased competition in the market, it becomes more important to limit these costs.

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

The work presented here is based on several industrial and research projects. A more technical description of the underlying data structure is given in Hintze, Schumann, and Stuering (2001). Lessons learned in implementing a distributed training environment are presented in Bluemel, Schenk, and Schumann (2002). Furthermore, the utilization

of an expert system to deal with complex scenarios was examined in Heutling, Schumann, Stuering (2003). This paper will focus on the education approach used to present knowledge in a virtual environment.

2   THE TRAINING ENVIRONMENT

There are several approaches to show how computers can be employed to enhance traditional learning and training methods. Using 3D CAD systems to develop new products is currently state-of-the-art in industry. In addition to support the design and construction of new products, most of the CAD systems provide the opportunity to define animations and render video sequences of the equipment still being developed. These video sequences can already give an early impression of the future product and can help to understand its functions. In this way, rendered video sequences can be seen as a simple learning aid.

However, the disadvantage of any animation or video sequence is the lack of user interactivity. For this reason, there is a variety of computer-based training software available that provide more interactivity. The flexibility of these systems varies greatly. It can be anywhere from a pre-defined structure of training lessons where you only can fill-in your content to a very flexible learning software providing its own application programmers interface that completely allows you to modify its appearance and behavior. Here, the trade-off is typically between desired flexibility and the complexity of the programming effort. Commercial off the shelf products are great if they exactly provide the functions you need but otherwise you can easily end up spending considerable efforts on programming your own customized solution.

The situation is more or less the same with simulation systems. There are highly advanced systems available to simulate practically all types of dynamic processes. But again, user interactivity is often quite limited. Typically, the simulation model will be developed by a simulation expert and afterwards simulation runs are executed without much user interaction. Of course the user can change the model parameters, but in most cases this results in a re-run of the simulation execution. So from this point of view, there is still no user interactivity during the simulation run. From this stating situation, we set our goal for developing a new interactive virtual training environment. We focused on the following goals:

- *Interactivity:* A major requirement was to support "learning by doing". This can only be realized if the trainee is actively involved in the training activity. Therefore, the training environment should allow for trainee interaction whenever feasible.
- *Flexibility:* The training environment should not become a single purpose application it should foster a wide range of different training scenarios.

- *Authoring:* Typically, most of the training systems that are in use today require both programming and training experts. The training expert provides the didactical and technical knowledge of the training content, the programming expert knows how to implement the training content in the training system. Another goal for the development of our training environment was to enable the training experts to create training applications themselves without writing much programming code.

The next chapter describes the system's architecture.

3   THE SYSTEM'S ARCHITECTURE

There are three main components that altogether form the training environment:

- *Scenario:* For each situation (e.g., training a maintenance technician to repair a printing machine) there is a certain amount of application specific data that completely represents the virtual model (e.g. of the printing machine) including learning objectives, failure possibilities, modeling of the machine's behavior, etc. This data can be further categorized into geometry, materials, movement possibilities, criteria and reactions for causal part relations, procedures (e.g. the steps required to disassemble a pressure cylinder), contextual help, etc. The entirety of this application specific data loaded into the virtual training environment forms what we call a training scenario. All data relevant for a particular scenario is stored in a digital document and is referred to as the Scenario Data File.
- *Scenario Player:* In addition to the application specific data, there is also a common set of functionality needed for handling and interacting with the objects in the virtual environment. Examples of common functionality includes loading and interpreting the Scenario Data Files, grasping and manipulating objects, navigating in the virtual world, applying tools to virtual objects, making decisions, etc. These functions are implemented in a program, which we call the Scenario Player. The Scenario Player is used for an type of training scenario. For instance, the same Scenario Player can be used training the maintenance of an oil press or for training the replacement of a bearing in a printing press.
- *Authoring Tool:* The behavior of the complex machines and equipment is taken into consideration when creating the scenario; meaning that the design of a complex data structure places high requirements on the consistency and fluidity of the image. To effectively accomplish this, a specific language was developed that facilitated the modeling process with its concept generation. How-

ever, to simplify the scenario building, an Authoring Tool is available that supports the author in building the scenario. Both the new language and algorithm usage facilitate the visual integration with the Scenario Player.

Using this architecture we were able to achieve our development goals. The Scenario concept not only allows for inclusion of a variety of interactive elements, but it is also the key for the flexibility. By loading different scenario data, the training environment can be easily adapted to other training applications. The authoring tool assists the training expert in specifying the training content and minimizes the need for programming.

The next chapter describes the different training modes facilitated by the training environments. The training modes are used to gradually introduce interactive elements in the scenario as the trainee advances in the learning process.

4   ADAPTING TO THE TRAINEE'S KNOWLEDGE

An essential requirement for any type of learning software is its capability to adapt itself to the knowledge of the trainee. Our training system allows the author to specify the learning content in four different training modes. The major characteristic distinguishing these modes is the amount of user interactivity. If a trainee is not familiar with the content of the training lesson, the system will visually present each step to the trainee without requiring any interference from the trainee. If the trainee, however, is very experienced the training system can be used to test the trainee's knowledge by letting the trainee do all interactions in the training scenario. The remainder of this chapter will describe the training modes in more detail and gives examples of how these modes have been employed in actual training scenarios.

4.1   Presentation Mode

On the scale of required user interactivity, the Presentation Mode represents the lower end. This, however, does not mean there is no user interaction possible! At any time, the trainees can stop the presentation and move around in the scenario to watch a certain step from a different viewpoint. Furthermore, the trainees can use the interactive procedure player to have the system repeat a certain step or to skip forward or backward in the sequence of steps. In other words, the Presentation Mode does not require the trainees to interact but if they desire they can do so by using the procedure player.

Typically, the Presentation Mode will be employed to introduce trainees to a new training scenario. The system will start from a defined initial situation and let the trainees observe all the steps leading to the final solution of the task.

Figure 1-3 show one single step of an actual aircraft maintenance scenario (Aitram 2003). Before, the trainees can start with the maintenance task, they have to follow the job set up procedure and place safety barriers at well defined positions beneath the aircraft's wing.

Figure 1 depicts the starting situation. For easier identification, the safety barriers are marked with a red circle in the picture. A brief description of the training step is displayed in the upper part of the screen. The procedure player is visible in the lower left part of the screen.

Figure 1: Initial Situation

When the trainees press the play button (marked red in Figure 2) the training system starts the demonstration and the safety barriers are moved one after another to their dedicated positions.

Figure 2: The System Displays the Correct Position of the Safety Barriers

In Figure 3, the final situation of the step is displayed. The safety barriers are placed in their correct positions. The "OK" message in the upper left part prompts the trainees to confirm when they are ready to proceed with the next step.
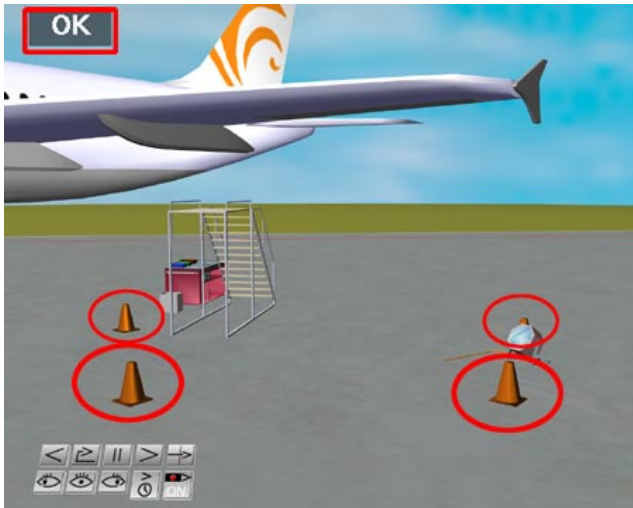

Figure 3: End Situation of the Step

Alternatively, the procedure player can be used to repeat one or more steps. Moreover at the end of each step, the trainees can move around to examine more closely what has been accomplish as the result of the current training step. The scenario author can support this exploration by defining specific view points to guide the trainees.

This sequence continues until the trainees have approached the final step of the procedure.

4.2 Guided Mode

The Guided Mode provides even more interactivity. Trainees should use the Guided Mode if they have completed the Presentation Mode and have reached a certain level of acquaintance with the training scenario. At least the should know the sequence of step and their corresponding content.

It is up to the scenario author to define how much support the system provides in Guided Mode. At the beginning of each step, the system displays a brief textual description about what to do. The contents of the guidance can be diverse. Among other element the scenario author can:

- Define viewpoints to guide the trainees.
- Introduce sub goals to give the trainees feedback about their learning progress.
- Provide helpful comments that the trainees can ask for.
- Prepare animations that demonstrate what should be done.

In the case of the step presented here, the scenario author defined the animation of moving the cones to their right positions to be the system's response. By clicking on

Figure 4: By Clicking on One Safety Barrier, the System Response Is Activated

one of the safety barriers, the trainee correctly accomplished the step. Therefore, the description of the step in the upper left part of the window is replaced by a confirmation message ("OK"). This is displayed in Figure 5.
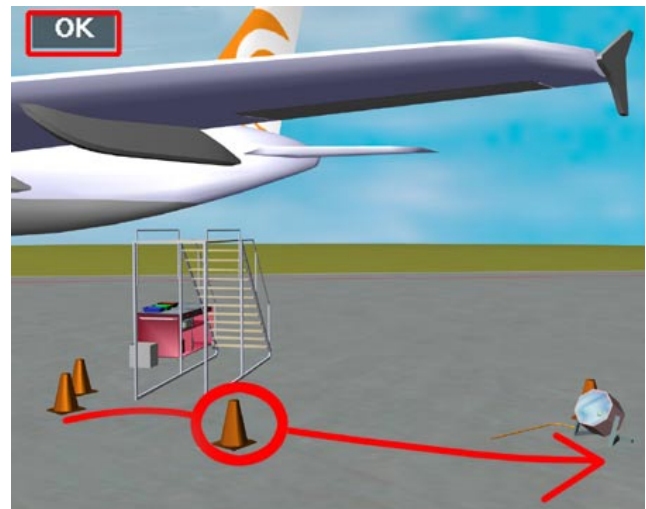

Figure 5: The System Demonstrates Where to Place the Safety Barriers

Figure 6 shows the situation at the end of the step. Obviously, there is not much difference to Figure 3. The only distinction is that there is no procedure player.

In Guided Mode, the trainees are requested to carry out all step of a procedure in the right sequence. Therefore, they are not allowed to use the procedure player to repeat or skip any steps.

4.3 Free Mode

The Free Mode was designed to allow a realistic assessment of the trainees learning progress. It determines
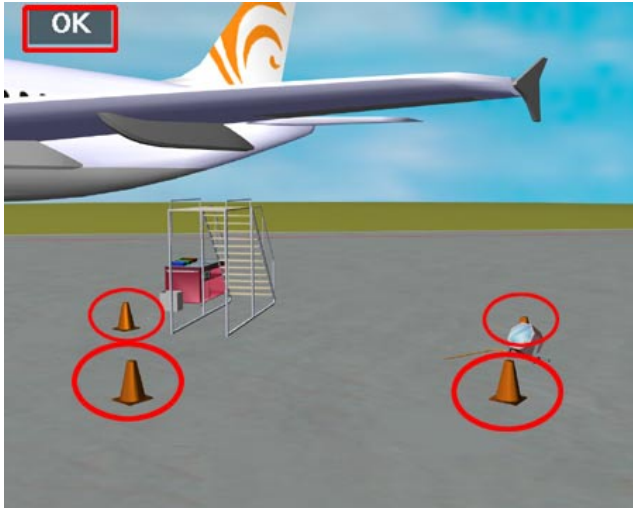
Figure 6: Safety Barriers in Their Final Positions

whether trainees are able to perform a task on their own without requiring assistance.

Consequently, there is no automatic assistance provided by the system. Nevertheless, supporting information is available on the trainees' request. Access of this information is reported to a log file that can later be viewed by the trainer.

In Free Mode, the trainees only receive a brief description of their task. They have to carry out all necessary actions themselves. This includes the possibility to make errors, to "violate task constraints", and to find an alternative way from the initial situation to the final situation that has not been foreseen by any scenario author.

For example, the training step described above to illustrate the Presentation and Guided Mode is part of the job set-up procedure for the installation of a new aileron servo control. This procedure is correctly finished if all items belonging to the job set up procedure are put in place.

The scenario author needs to define a criterion that the system can check after each user interaction to determine whether the task was successfully completed.

4.4 Discovery Mode

In discovery mode, the emphasis is on individual learning and understanding. There is no current task to solve. Hence, there is also procedure active. The trainee is allow to do free interactions and explore the scenario.

5 THE SCENARIO AUTHOR'S VIEW

Whereas Chapter 4 provided how the scenario is presented to the trainees, this chapter gives a brief introduction of the scenario authors' task.

No matter what training mode is used to present the scenario, all modes have in common that they are based on the same graphical objects. The 3D geometry of the scenario objects is imported from other 3D systems using standard file formats. It is important to define separate geometric shapes for each object that the trainees can manipulate individually.

For instance, all four of the safety barriers can separately moved to an individual position in the virtual environment by the trainee. Therefore, the scenario author needs to create four scenario objects with different names to represent the barriers. For each object, a reference to its geometric shape needs to be added. The remainder of the chapter will describe the other scenario elements used to implement the different training modes.

5.1 Presentation Mode

For each of the safety barriers a time curve is created to define the path on which the barriers moves to its specified position. All four time curves are gathered to form a functionality. The functionality contains information pertaining to which objects should be moved when and on what time curves. To make it easier for the trainee to follow the animation, barriers are moved to their final positions one after another. This sequence is specified in the functionality.

Now the scenario author needs to specify when the system should activate this functionality. This is accomplished by defining a new training step. Among other information, the step's definition includes a reference to a functionality that the system will execute when the step is displayed in Presentation Mode.

5.2 Guided Mode

A little more information is needed in Guided Mode. Since the trainee should be able to interactively accomplish the step, a criterion is needed allowing the system to check the trainee's success.

One way of doing this, is to define a criterion that constantly compares the current position of the barriers against their required final positions. The criterion's definition for a single barrier might look like:

```
Dist( TRAN_LT,
    Barrier_01:Barrier_01;
    Field:PosBarrier1;
    0,5 )
```

In order to give the trainee more assistance, the scenario author can add a trigger to the safety barriers that is activated when the trainees click on them. The trigger starts a functionality that was already used in presentation mode.

5.3 Free Mode

In free mode, the trainees have to accomplish the task by themselves. There is no procedure active to guide the trainees from one step to another. The system evaluates the task constraints to decide whether or not the trainee has cor-

rectly finished a task. To be more specific, the scenario author can include one or more sub goals to give the trainee a more detailed feedback (Figure 7).
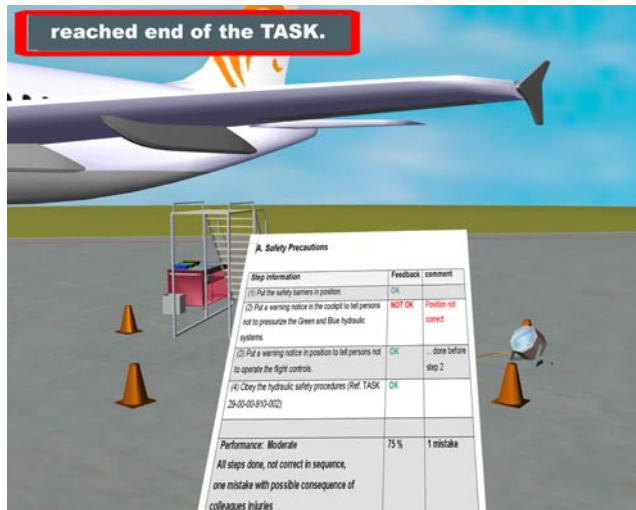

Figure 7: Final Evaluation in Free Mode

The amount of interactive elements in Free Mode depends on the scenario author. Theoretically, only the amount of modeling effort and the computer's performance determine how close to reality the virtual scenario can get. In practice, the scenario author will introduce interactive elements according to the learning goals. This could also include allowing the trainees make mistakes to find out what would happen if they did this in reality.

5.4 Discovery Mode

From the author's point of view, there is no specific modeling necessary to support the discovery mode. This mode is meant to let the trainees learn by exploration. Trainees are free to move around in the scenario. There is nothing the system asks them to do in free mode. For instance, they can use the object browser to learn about the shape and size of single components. The Hierarchy Browser allows for viewing the components of assemblies. If trainees desire, they can use the functionality provided by the scenario author in the other modes to view how a machine works or they can also decide to turn off all constraints, or select parts in transparent view to observe the inner part of an assemblies. These are only a few examples of the powerful functions of the free mode.

6 CONCLUSION

The paper presented an interactive, virtual training environment specifically developed to support training and maintenance task of complex technical equipment. The architecture of the system was briefly described. Further-

more, the paper explained the different training modes according to the different learning goals a scenario author wants to convey. The last chapter gave a short glimpse into the scenario author's work.

From our point of view, the new and innovative aspect of this training environment is the way the technical processes are modeled. Instead of just displaying an animation, the system keeps track of the underlying scenario status. This allows a trainee to be actively involved in a training scenario. The trainees can take over the training procedure at any time if they know what to do or they can have the system show them each step in detail. Our approach uses the freedom of virtual reality to let the trainees learn by doing and exploring in a new manner.

ACKNOWLEDGMENT

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AUTHOR BIOGRAPHIES

EBERHARD BLUEMEL is Head of the Division of Virtual Development and Training at the Fraunhofer Institute in Magdeburg, Germany. He holds a Ph.D. in the natural sciences from the Technical University of Magdeburg. His research fields include discrete optimization, operations research, logistics, simulation, and Virtual Reality.

AXEL HINTZE graduated as a mathematician from the University of Magdeburg in 1976, where he also received his Ph.D. in natural sciences (mathematical analysis) in

1981. For 15 years, he was project-manager in the R&D department of a mechanical engineering company, where he did research on mathematical modeling and the simulation of technical processes, animation and Virtual Reality for the mechanical engineering industry. Now Head of the Department of Virtual Systems at the Fraunhofer Institute in Magdeburg, he oversees applied research in the field of Virtual Reality.

TORSTEN SCHULZ graduated as an industrial designer from the University of Arts Berlin in 1990. His fields of research are Virtual Reality interface design and cognition of virtual interactivity. An associate in the Department of Virtual Interactive Training at the Fraunhofer Institute in Magdeburg, he is in charge of developing training based on Virtual Reality for international research projects in different industrial fields.

MARCO SCHUMANN is an associate at the Fraunhofer Institute in Magdeburg, Germany. He holds a Master's degree in Computer Science from the Otto-von-Guericke University Magdeburg. His experiences in developing simulations and applications for the Internet include a one-year stay at the University of Wisconsin, Stevens Point. His primary research interest is the application of simulation methods in factory planning and distributed virtual training environments.

STEFAN STUERING is Head of the Department of Virtual Interactive Training at the Fraunhofer Institute in Magdeburg. He graduated from the Technical University Munich in 1993 and has been in charge of the project management of several national and international applied research projects in the fields of Information Technology and Virtual Reality.