Virtual Reality Platforms for Education and Training in Industry

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Abstract. Developing, testing and operating complex machinery and repairing it under time pressure if it breaks down are some of the new skills, professionals in many occupations have to learn as quickly as possible. Actions on machinery and plants are trained in individual lessons on an immersive virtual model. This paper introduces the methodology behind the technical solution and presents experiences acquired during its implementation with a virtual learning platform for operators and maintenance staff as examples.

1 The Fraunhofer IFF Learning Platform

1.1 General Concept

The training concept upon which the Fraunhofer IFF learning platform is based allows customizing training to match future operators' levels of knowledge by variably configuring the level of difficulty on the basis of the level of interaction. A process to be learned can be explored initially in a model solution. First, learners are introduced to the entire process as well as its interactions with other subsystems. After that, learners are requested to execute the process, independently completing a task by interacting with the virtual system. The learning platform's system initially supports them by continuing to issue concrete instructions on completing the individual process steps.

Afterward, learners ought to be able to execute the assigned tasks without the system's help. The learning platform logs all of a learner's activities as well as the time and number of attempts required to complete a task. This information is referenced later to assess training performance.

The Fraunhofer IFF has developed a software platform that enables training and interaction with realistic virtual products, machinery and plants on the basis of 3D immersive virtual environments. A new technology has been produced that enables trainers to conduct and trainees to partake of theoretical and practical training on complex models individually and technical training in teams in distributed environments without having to revert to real objects. The recognition value of the visualization, the realism of the simulation of a product or plant's

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behaviour and options for realistic user interaction are essential. Numerous cross-industry solutions for virtual interactive learning platforms for different training and educational objectives ([1], [2], [5], [7]) have been developed.

A Tutoring System for Web-Based and Case-Oriented Training in Medicine is presented in [4]. It includes a training system that is based on three different models:

- Tutoring Process Model
- The Case Knowledge Model
- The Medical Knowledge Model.

Those models are chosen and adapted to the domain of medicine. Although it is very domain specific, it shows certain parallels to the approach presented in this paper, e.g. a knowledge base that allows users to receive information on demand and a guided learning tour that supports the learning process step by step.

The IFF training solutions are conceptually based on the precise objectives of the VR learning environment for the case of application and the methodical analysis of the skills to be learned (perception, orientation, skills, communication, etc.), users' personalities and learning styles and the structure of the course to teach the training objectives. The underlying concept is based on the methodical analysis of various assembly and maintenance tasks and classified features of applicable training environments based on virtual technologies that serve as the starting point for modeling a learning environment. This concept requires a supporting VR system architecture.

1.2 The Layered Architecture

A technical system must be modeled realistically to obtain realistic training conditions. Thus, a model should react and also respond to user actions just as the real equipment. Users must be enabled to perform every relevant action they would in the real world in the simulated environment (cf. [3]). A great deal more information has to be modeled in addition to the objects' geometry, e.g. the hierarchy of objects and possible parenting relationships, constraints on movement, causalities, properties, actions and dynamic behavior. Furthermore, components are needed to enable trainees to evaluate their actions themselves and to facilitate communication between trainees and instructors.
The information needed to model a training environment can be divided into three levels (see Figure 1).

- Geometry level: This level includes every type of node (geometry, animation, trigger, level-of-detail switches, etc.) common to the scenario structure of most existing VR systems. These entities provide the formal basis for implementing a scenario in a runtime system. Suitable converters import the information on this level from other systems such as CAD applications. Engineers, instructors and educators normally do not have to know details on these levels.

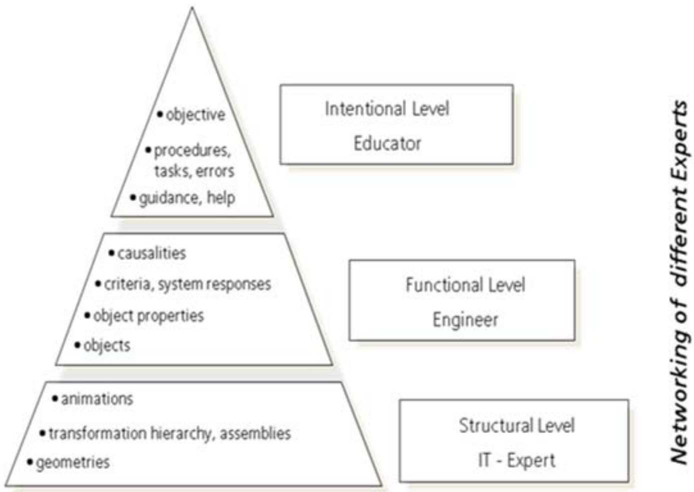

Fig. 1. The levels of the VR scenario concept

– Object level: This level is the domain of design engineers and contains the technological know-how specific to a system.

  The object level contains all information specific to a product already defined in the design process. It also includes characteristics determined by natural constraints, e.g. gravity, collision detection/prevention, etc.
– Instructional level: This level is the domain of educators or instructors. Objects defined on 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.

All three of the aforementioned levels are interdependent and each level requires specialists from different fields.

Suitable tools that fulfill both, the technical and functional and the pedagogical and didactic aspects of the content, are needed to implement the substantial technical know-how required for existing technical options, cost effectively as well. To attain the high flexibility required by the applications developed, the components were divided in:

– Authoring system: The authoring system provides trainers support when they create training scenarios. The authoring system is intended to provide trainers a tool that requires a minimum of knowledge of computers. Unlike most training systems developed by computer experts, this application is intended to grant experts in the field of training diverse options for creativity.

– Scenario data: Work with the authoring system produces a training scenario saved as a scenario file containing the specific data for a concrete training task.
– Runtime system: The runtime system is essential to conducting training. It is independent of the concrete training scenario and can be equally applied to every scenario created with the authoring system. One runtime system instance is required for every trainer and trainee.

Building upon this work, the Fraunhofer IFF developed tools that simplify the creation of training scenarios from the conversion of design data up through the creation of complex causal chains to define training objectives and generate training tasks even without knowledge of complex programming.

2 Best Practice Examples: Virtual Interactive Training for RWE AG

In the course of refining its internal training concept, RWE's Technik Center Primärtechnik (TCP) decided to collaborate with the experts from the Fraunhofer IFF Virtual Development and Training Centre VDTC.

The specific constraints of ongoing technical operation, which make training in real situations quite difficult, were the reason for doing so. One far-reaching problem is the relative impossibility of using sensitive equipment in operation, in this case transformers, for training for reasons of safety and because they are integrated in national or international power grid structures. Moreover, the pertinent safety regulations must always be strictly observed whenever inspection, servicing, maintenance and improvement work is being performed. This also complicates training considerably. In addition, it is impossible to really observe functional processes inside equipment. Therefore, specialists need a high degree of technical knowledge and the ability to think abstractly to understand them.

In the end, the stations' decades-long service life necessitates developing the know-how of the technical specialists for the company and making it useful for future generations. This must be done as simply, vividly and standardized as possible.

1. Preparation of a Transformer for Rail Transport
   The TCP uses a VR scenario of an extra high voltage grade power transformer of up to 200 MVA in the 220 kV capacity class. It shows interactive animations to train operators how to unplug it from the grid and disconnect the important elements (cf. [1]). These operations prepare the main transformer body for transportation and future use. The objective is for trainees to learn, train, comprehend and internalize the work procedures (see Figure 2).

   Given the high risks connected with the procedure, it is essential to demonstrate the correct sequential order of work incorporating safety regulations that guarantee safe conditions (cf. [1]). VR immerses trainees in

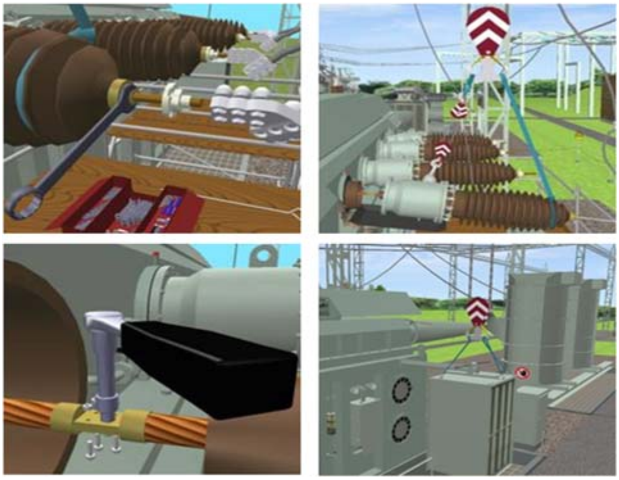

Fig. 2. Steps of the work procedure

realistic simulated environments. This can provide work experience without any risk of accidents or maloperation. Learning and interacting with VR is more efficient than traditional methods.

2. Replacing a Buchholz Relay
Transformers are critically important equipment and their condition affects operations. A Buchholz relay is an important device that protects and monitors liquid cooled transformers and compensation reactors. It is easy to operate, highly reliable, maintenance free and long lived.

A relay is installed in the connecting pipe between the transformer tank and the conservator tank (see Figure 3). In normal operation, it is filled completely with insulating liquid. The float is buoyed to its highest position. In reaction to malfunctions inside a transformer, a Buchholz relay collects the

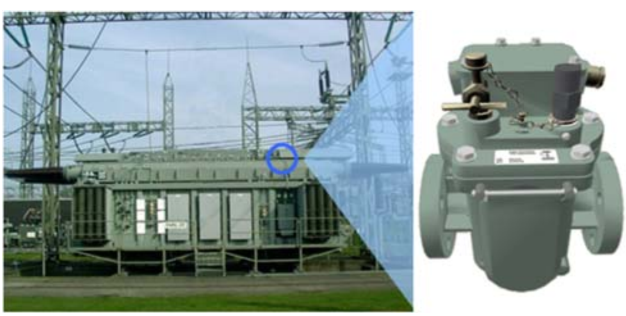

Fig. 3. Buchholz relay in a transformer

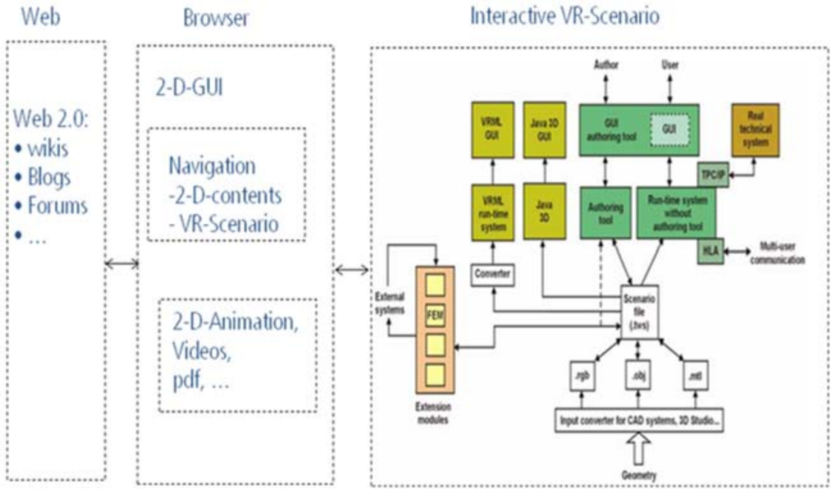

Fig. 4. Architecture of an integrated learning platform

free gas present in the insulating liquid, leaks insulating liquid and discharges the insulating liquid flow induced by a pressure wave in the direction of the conservator tank.

The training covering the Buchholz relay teaches trainees:

- What a Buchholz relays function in a transformator is
- How a Buchholz relay responds to a malfunction and
- How to replace/repair a Buchholz relay.

These three topics place different demands on the visualization and didactic treatment, requiring a flexible learning platform.

An integrated browser presents existing training materials such as operator manuals, 2-D animations and videos. A bidirectional connection between the VR scene and the browser contents allows systematically opening required information in the 3-D scene and additionally establishes a connection between the 2-D documentation (e.g. sectional drawing) and 3-D representation (see Figure 4). In addition, supplementary information such as user guidance can be presented formatted as a graphic and adapted to the client's corporate identity and easily used through common forms of interaction (e.g. links).

Practical training can be conducted with a flexible number of trainees, largely any time and any place. Both the schedule for exercises and the focus on individual work steps may be varied as desired. Errors do not have any negative consequences in the virtual scenario, what is equipment of the same design is being used, standardized operations can be applied anywhere without any "translation problems".

3 Summary

Virtual reality technologies have experienced a sizeable leap in development in recent years. Extraordinarily complex realities can be reproduced with the aid of VR. The Fraunhofer Institute for Factory Operation and Automation IFF is home to interactive high-level VR environments that can be specially applied in a broad range of industrial training programs ([cf.[2]). Both the basic technological and economic conditions will make broad use of interactive VR technologies in the basic and advanced vocational training of technical specialists possible in the near future. From the perspective of research, this is an impetus for research and development plans to intensify their focus on the potentials of learning in VR work environments. The technological developments presented here facilitate training on realistic virtual products, machinery and plants even when access to real objects, which are often not available for training at all or only to a limited extent, is limited. The use of VR systems in distributed learning environments is equally possible. The theoretical construct constitutes the foundation for researching the didactic and technical potentials of implementing VR systems and their potentials for education. A conceptual theory for research on learning actions in real and virtual technical systems is being worked on.

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