A Design Procedure for Safety Simulation System Using Virtual Reality

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Abstract

One of the objectives of any task design is to provide a safe and helpful workplace for the employees. The safety and health module may include means for confronting the design with safety and health regulations and standards as well as tools for obstacles and collisions detection (such as error models and simulators).

Virtual Reality is a leading edge technology which has only very recently become available on platforms and at prices accessible to the majority of simulation engineers.

The design of an automated manufacturing system is a complicated, multidisciplinary task that requires involvement of several specialists. In this paper, a design procedure that facilitates the safety and ergonomic considerations of an automated manufacturing system are described. The procedure consists of the following major steps: Data collection and analysis of the data, creation of a three-dimensional simulation model of the work environment, simulation for safety analysis and risk assessment, development of safety solutions, selection of the preferred solutions, implementation of the selected solutions, reporting, and training When improving the safety of an existing system the three-dimensional simulation model helps the designer to perceive the work from operators point of view objectively and safely without the exposure to hazards of the actual system.

1.What is Virtual Reality

VR is the term used to describe methods of involvement and interaction for humans with a computer-generated graphical (usually 3D) environment. Normally referred to as a VR world(Virtual Environment, VE), this environment is experienced by a human participant through the use of special VR equipment. In simulation terms, VR can be thought of as an advanced user interface to 3D simulation models [7]

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VR equipment provides the human with sensory information about the VE. This can include 3D viewing, sound touch and smell which have all been employed to stimulate the senses so as to increase the illusion that the human is a participant in this VE. The objective of the technology is to obtain a level of human involvement (sometimes referred to as immersion) with the VE that is suitable to the task at hand. Different tasks require different levels of involvement. For example, airplane flight crisis simulator VR worlds are most effective when they persuade the human to generate an emotional involvement with the situation. Scientific VR worlds designed to promote insight and analysis do not usually require this level of emotional involvement.

As important as reception of information by the human senses is, it becomes much more valuable when the human can interact with the VE. VR equipment allows the human to change position and orientation in the VE. This is the equivalent to "moving" through the VE. There is also the capability to interact with the VE, obtaining information and making instantaneous changes to the VE.

2. Applications of VR

Useful applications of VR include training in a variety of areas (military, medical, equipment operation, etc.), education, design evaluation (virtual prototyping), architectural walk-through, human factors and ergonomic studies, simulation of assembly and treatment of phobias (e.g., fear of height), art, entertainment, and much more[5]. In this paper, safety design and analysis using VR is proposed as another useful application of VR.

Virtual reality applications need all the system power they can get. Therefore virtual reality systems have to deal with a number of different and physically displaced hardware devices in order to exploit existing resources. Figure 1 shows a typical set of devices and computing nodes that are handled by such systems [9].

The graphic workstation requires a two-channel video board that drives a head-mounted-display(HMD) for individual experienced and a large screen projection for a larger audience. A tracking system monitors the position and orientation of the HMD, body positions, and various interaction devices. Multimedia-workstations and special-purpose audio hardware output to headphones for the individual experience and to a speaker system for the larger audience.

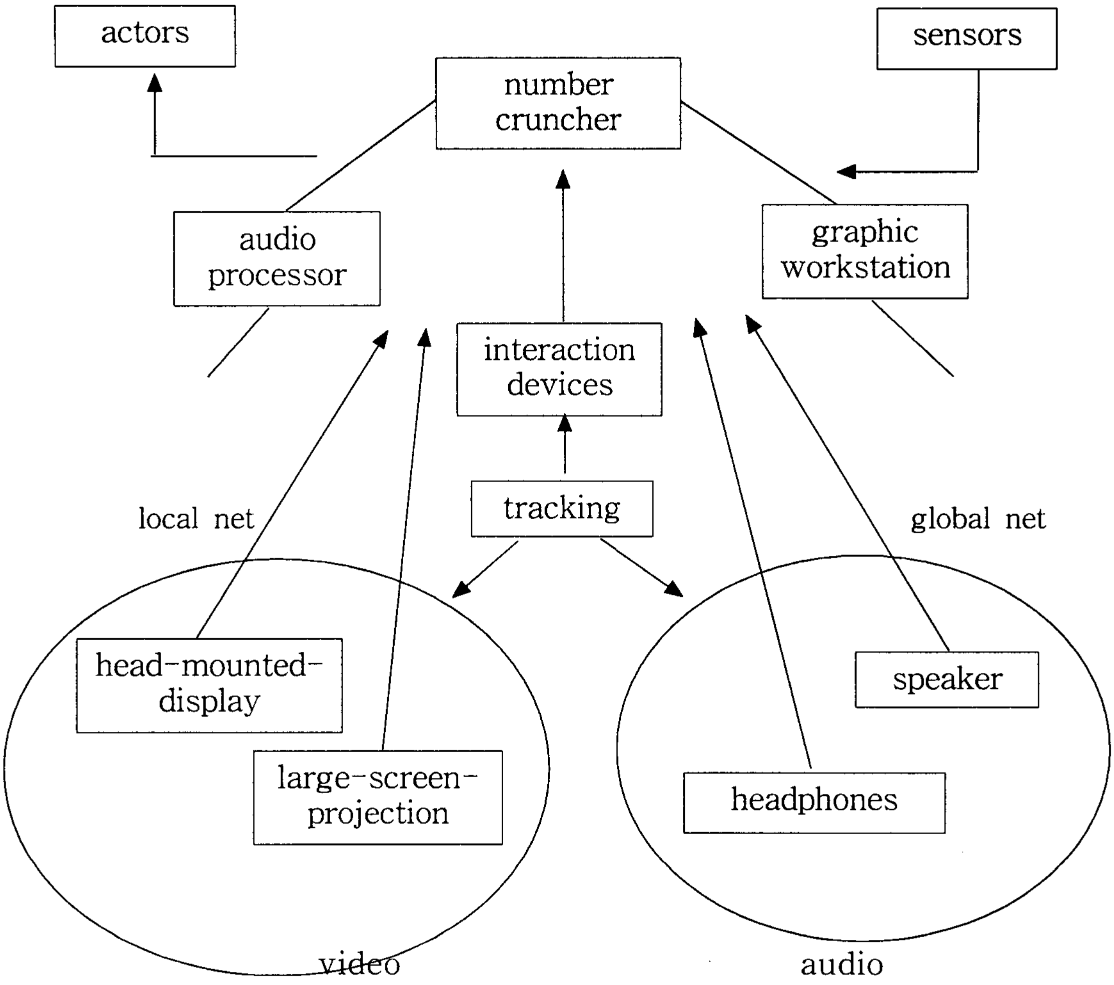

Fig. 1. Device configuration for virtual reality

3. VR in process design and analysis for safety

Automated manufacturing systems with complex and wide-ranging functions are difficult to visualize. It is also difficult to demonstrate the advantages and disadvantages of alternative design solutions as well as the need for a complementary safety system . By proper selection and design of safety devices it is possible to increase the reliability, performance, and utilization of a manufacturing system. An effective combination of system functions and manual tasks requires proper work design and development of work teams.

The design of an automated manufacturing system, such as a robot system, is a complicated multidisciplinary task that requires involvement of several specialists [1, 6, 10]. It is important for the operator that the system is safe and reliable.

The representation and direct manipulative capabilities of VR technology seem particularly appropriate for visualizing and assessing complicated physical production facility constraints while also determining optimal process flows and safety devices. In design and simulation of production systems economic and operational aspects of the system should be considered concurrently. Some of the operational issues confronting system designers include the ability to operate equipment and machinery safely and efficiently, the ease and speed of moving materials, equipment, tools, and work pieces within the facility, and the capability to easily accomplish the next wave of changes in the arrangement of equipment and machinery.

One can argue that most of these features would also fit into more standard, 2-dimensional factory simulation packages. These programs have a great advantage over VR in terms of cost, history of application(i.e., they are well tested), and, in many cases, ease of use. Instead of donning cumbersome hardware and grabbing virtual equipment in 3D, why not just grab machine icons with a mouse and drag them across a 2D window ?

The answer depend on the nature of the problem. For many applications, two dimensions are adequate and desirable. However, when working with highly constrained spaces, having the third dimension can be critical [4, 14]. Especially, when working with highly dangerous and complicated workplace like a nuclear power plant, VR can serve the solution to improve the quality of work place and method. Using VR, one can teleoperate some dangerous tasks at such workplace.

A design procedure that facilitates safety and ergonomic considerations of a complicated system is described in this paper.

4. A Design procedure for safety

The systematic design process generally consists of the following basic steps [8, 13]:

1. Selection of a project and objectives definition.
2. Definition of measures for evaluating the design in view of the objectives.
3. Determination of the project limitation and freedom of action.
4. Data gathering and presentation.
5. Analysis of the data
6. Development and presentation of alternative methods.
7. Evaluating alternative methods and selection of the best one.
8. Detailed design and presentation of the selected method.
9. Implementation of the designed methods (work place and method).
10. Following up the method.

The safety design method for an existing manafacturing system comsists of the following major steps referring to the above steps :

1. Data collection and analysis of the data.
2. Creation of a three-dimensional simulation model of the work environment.
3. Simulation for safety analysis and risk assessment.
4. Development of safety solutions
5. Evaluation of the solutions
6. Selection of the preferred solutions.
7. Implementation of the selected solutions.
8. Reporting.
9. Training.

4.1 Data collection and analysis of the data

The available documentation and other data regarding the system, products to be manufactured, tasks, available space, etc., is obtained. This includes an accurate definition of the task that has to be designed (or redesigned, in the case of an existing system), the objectives and quantitative criteria for the design and the limitations imposed (i.e. budget limitations).

Based on the collected data, the data are analyzed in view of the defined measures and ergonomics. Haslegrave and Corlett [2] addressed the importance of work and workplace design on health, safety, and quality performance. They surveyed means for evaluating risk of injury. Hale, Stoop, and Honmels [3] claimed that safety faults should be detected by a means such as human error models, as an integral part of the design process.

4.2 Creation of a three-dimensional simulation model

Considering these analyses, a three-dimensional simulation model of the automated manufacturing system is created [12].

The three-dimensional model consists of the layout of the manufacturing system and the human operator. The robots of the system can be programmed to simulate their work sequences. Also the work done by the human operator and the connections to the work sequence of the robots can be simulated. In addition, the movements of other parts of the system, such as conveyors, cranes and hoists, and safety devices, can be defined and simulated.

When the safety system is still at the design stage, before any safety devices have been installed, the realistic three-dimensional simulation model forms a good basis for design and evaluation. Design flaws can be detected earlier before anything has been built, and the modifications will be less costly.

4.3 Simulation for safety analysis and risk assessment

Using the rendering software and VR devices for interactive control of 3-D model, several alternatives can be simulated to analyze and assess the 3-D model of the safety and risk in real time.

A questionnaire safety analysis for manufacturing automation was developed based on a long term development work in VTT. The method combines the features of the Energy Analysis Method and the Failure Mode and Effect Analysis . These features were complemented with the requirements included in the international ISO-standard concerning robot safety. The method is based on the checklist. Hints based on experiences of previous safety analyses are provided with each checklist item.

The checklist is divided into four sections:

1. Structural hazards (power source, noise and vibration)
2. Hazards within the work envelope of moving parts (impact, pinch-point and cutting hazards. falling objects, etc.)
3. Hazards reaching beyond work envelope (hurling objects, radiation, chemical hazards, explosion)
4. Work environment and work (falling from structures. physical or mental strain)

At least the following safety aspects should be considered in the analysis: System traffic (i.e. all traffic, whether persons or materials, inside the system area), materials handling, and operator tasks performed in the system area, such as setup, maintenance, loading and unloading of parts, disturbance control and troubleshooting, and cleaning. In order to analyze complex systems, it may be necessary to divide the system into smaller sections, and to perform separate analyses for each section.

The risk of each identified hazard is assessed by assigning values (ranging from 1 to 3) for the probability of occurrence of an event that can cause harm and for the severity of the possible harm. The risk index is calculated by multiplying the probability value by the severity value.

When the entire system is still at the design stage, safety analysis and risk assessment can be tentatively done by using the three-dimensional simulation model. It is obvious, that the analysis based on the simulation model should be done by identifying only the hazards listed in the checklist sections 2 and 4. Hazards with low probability of occurrence, and which are difficult to identify not only from the model but also from the real system, should be addressed by creating instructions and proven technologies.

Kuivanen [5], Kuivanen [6] compared the number of identified hazards by using the computerized model of the system and by analyzing the actual system. Five designers participated in the study. There were no significant differences in the safety analyses based on the model and the real system regarding the number of identified hazards and risk assessment. This indicates that it is possible to make a reliable safety analysis based on a computerized simulation model long before the real system exists, and before the investment decision is made.

Safety analysis and risk assessment should be done in cooperation with the designers and/or operators of the system. At least, the identified hazards and assessed risks should be discussed with them.

When the safety design is done for the existing manufacturing system, the safety analysis, naturally, done on the shop floor by observing the actual system. However, the three-dimensional simulation model facilitates the design, evaluation and demonstration of the safety solutions.

4.4 Development, evaluation and selection of safety solutions

The alternative solutions for safety devices are created by using well-tried safety principles and experiences from good earlier solutions. The solutions are adapted to the requirements of the robot system and their functionality is tested by aid of the simulation model.

The solutions are evaluated together with the designers and operators of the robot system. The preferred solutions are selected and the necessary modifications are made. The functionality of the solutions and their effect on the operation of the entire system can be comprehensibly demonstrated by the aid of the three-dimensional simulation model.

4.5 Test, reporting and training

The selected solution is tested and reviewed under the decided testing condition. If the test is finished successfully, then the design solutions are reported together with the identified hazards and assessed risks. The solutions can be demonstrated by using the color print-outs of the computer screen, or by a video tape made of the robot system simulation.

The supervisor and operator training can already be started by the aid of the three dimensional simulation model. The model can be used to teach the operators how to operate the system, and how to perform the manual tasks safely.

5. Conclusions

Advanced computer technologies such as VR has been experienced to be a very effective tool in safety system design [11]. The introduced approach is based on various supporting tools such as 3D modeling and rendering softwares and devices in order to test and evaluate easily and interactively a large number of alternative designs in conditions that are very close to reality.

The three-dimensional simulation model can also be used to teach the operators to operate the system and to perform manual tasks safely.

The designer and the operators of the system can obtain a better overall picture of the system when using a three-dimensional simulation model than by using only static two-dimensional layout drawings. The model helps the designer to perceive the work from operators point of view objectively and safely without the exposure to the hazards of the actual system. In addition, different design alternatives can be modelled and analyzed relatively quickly and with low costs.

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