Design and Development of Adaptive Simulators Using 3D Modeling

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Abstract
The analysis of the effectiveness of adaptive training systems for training personnel to work in regular and emergency situations at the enterprises of chemical-technological profile was performed. It is concluded that for the chemical industry the simulators based on interactive 3D models of production facility are the most effective.

The analysis of the main causes of emergency in the chemical industries allows developing a structure of the automated information system, which is a major component of the training complex. The classification of all basic objects of the virtual space was performed to formalize approaches to create simulators based on interactive 3D models of production facilities. The combination of these sets of the main objects of virtual space together with many auxiliary facilities (light sources, animations, etc.) allowed to produce a formalized model of the virtual space of production facility.

The proposed theoretical approaches were implemented in the development of adaptive training complex for training personnel of chemical enterprises in the Tambov region, the Russian Federation. The developed adaptive training complex is focused on the use of 3D models of virtual reality. It also provides the possibility of training on the real object with the use of augmented reality technology.

Keywords: adaptive simulator, 3D modeling, visualization, training of personnel, chemical process systems

INTRODUCTION
The development of industry causes the necessity of upgrading equipment, creating new automated process control systems of technological process, and using advanced science-intensive technologies. This increases the level of responsibility of maintenance personnel for the operation of technical systems, when an error can lead to the occurrence of emergency situations, serious material losses, environmental disasters and human casualties. Reducing the likelihood of such errors is possible by increasing the level of competence of employees through continuous training based on modern information technologies. Automated information systems (AIS) make it possible to carry out both theoretical training of personnel in the main areas of their activity in normal and emergency conditions, as well as to provide practical training and acquisition of sustainable skills in managing a technical system [1].

The existing needs in training systems for the personnel of chemical process systems (CPS) are not fully met due to the lack of a unified system approach to their development, the impossibility of their replication for various industries, isolation from the real production process. In our opinion, adaptive simulators (AS) can be the most important components of this kind of system, which include all the necessary software and hardware elements for realistic immersion of trainees in virtual reality. They are also equipped with the AS adaptation subsystem to take into account individual psychological and physiological characteristics of trainees.

ANALYSIS OF APPROACHES TO 3D MODELING USE IN THE DESIGN OF SIMULATORS
The need for AS is conditioned by the specificity of the processes of chemical technologies, which consists in the use of toxic, explosive and fire hazardous substances. Operators must have strong skills in managing the CPS, diagnosing possible deviations from regular modes, identifying their causes, predicting possible consequences, making decisions to eliminate or localize emergency situations [2, 3]. Obviously, such skills cannot be obtained in conditions of real-world manufacturing.

The use of interactive 3D-modeling technologies makes it possible to study the location of buildings, structures, facilities, technological equipment, and simulate the occurrence of emergency situations so as to acquire practical skills of counteraction and localization of possible accidents. The development of full-scale simulators cannot be implemented for CPS due to its high cost, so the creation of the AS is the main method of improving the quality of training of the CPS personnel and ensuring reliability of their operation.

The need to use modern visualization technologies and 3D modeling in the development of simulators was confirmed by numerous examples of their successful implementation. For example, in [4] the structure of AIS modeling of oil spills emergencies was considered, and in [5] a vessel traffic simulation system was developed to give the characteristics of
ships, water surface, weather conditions, etc. The application of virtual simulation technologies for the analysis of the motion of orbiting satellites in real time was presented by the authors of [6]. 3D modeling is also widely used in medicine, for example, in analyzing the movements of patients to monitor the process of their rehabilitation [7], modeling of surgery using VR-technologies [8]. Thus, 3D modeling and visualization of various processes of human activity are the part in modern training standards for many areas. Training and use of these technologies make it possible to achieve a higher level of practical and theoretical competences, especially in the field of modeling human activities in emergency situations that are difficult to implement in the real world [9, 10], as well as in the military industry [11].

The creation of virtual simulators, laboratories, and modeling of technical systems and equipment bring the training of engineers to a new level [12], including through the implementation of such training systems as triage [13]. The use of modern computer tools makes it possible to create an optimal training course in terms of its complexity.

The reduction in the human factor influence on the occurrence of technological equipment failures and emergency situations is the most important factor in improving the reliability of industrial technical systems. This problem has become especially urgent in the last decades with the active introduction of innovative high technologies in the industry, which significantly increase the complexity of technical systems management. The number of emergencies caused by humans in chemical, energy, oil and gas industries, mechanical engineering and other industries is increasing year by year. The use of automation tools, decision support information systems, automated means of preventing emergencies is aimed at automating the management process and reducing the number of maintenance personnel, which in turn increases the requirements for the qualification of personnel.

THE STRUCTURE OF AIS TRAINING FOR TECHNICAL SYSTEMS OPERATORS

We consider the general structure of AIS training for technical systems operators. It is one of the main software components of the AS (Figure 1), including the following core modules [14]:

The Preset Module is intended for setting the initial parameters of the AIS operation, selecting the simulated technical system and product, identifying the trainee and the instructor.

The Reference Module includes help files for work with AIS training of operators; Description of production regulations; Drawings and schemes of technical systems; 3D-models of technological equipment, etc.

The Training System includes:

- Network interaction module
  - Operators’ interaction
  - Instructor-trainee interaction
  - Interaction with other modules

The Instructor Module includes:

- Task generation bar
- Perturbation bar
- States control bar
- Training protocol view bar

The Trainees Modules include:

- TS bar
- Control unit bar
- Call bar
- Information windows
- Interaction windows
- Help bar

The Analysis Module includes:

- Training result generation
- Identification of bottlenecks in training
- Interaction assessment
- Evaluation of emergency shutdown procedures

The Testing Module includes:

- Test tasks
- Test reports

The Database includes:

- Users
- Reports’ archives
- Standard processes prototypes
- Production regulations
- Equipment catalogs

The Knowledge base includes:

- Models of TS failures
- Models of TS operation
- Models of operators’ work

The Data analytical regulations for TS

Figure 1: The structure of AIS training for operators of technical systems of chemical processes
The Testing Module is used for testing trainees’ theoretical knowledge in the subject area.

The training system is designed to develop practical skills in technical systems management in normal and emergency modes, as well as to provide feedback and make evaluation of the training.

Within the framework of the AIS, we consider an example of the developed software for control panels of technical systems. This component allows not only to simulate real control panels, but also to provide joint training using network communication technologies. The LabVIEW programming environment was used for the software implementation.

Also, within the framework of this software, a module for 3D modeling of the operator’s working space was implemented, including the placement of technological equipment and control systems, workshop premises, production site and other elements of virtual reality. In this article, authors explore the approaches to the development of interactive 3D models and their application in AS for training of personnel in industrial technical systems. The Unreal Development Kit (UDK) was used as a development environment.

**MODEL OF VIRTUAL PRODUCTION SPACE**

When modeling a virtual production space, it is problematic to classify, create and place a plurality of objects in a scene using geometric transformations in accordance with the requirements for the model being created.

Authors consider the main objects of the virtual production space as a plurality of the following sets:

\[
VirtPr = Ter \cup BSP \cup Vol \cup StM \cup SkM \cup PS \cup AS \cup TXR \cup Mat \cup SC \cup LH
\]

where \(VirtPr\) is the modeled virtual production space;

\(Ter\) is a set of landscape objects;

\(BSP\) is a set of BSP-Geometry (Binary Space Partitioning) objects;

\(Vol\) is a set of Volumes;

\(StM\) is a set of Static Meshes, which are imported into the working medium from outside editors;

\(SkM\) is a set of Skeletal Meshes;

\(PS\) is a set of Particle Systems;

\(AS\) is Animation sets;

\(TXR\) is a set of Textures;

\(Mat\) is a set of Materials;

\(SC\) is a set of Sound Cues;

\(Lh\) is a set of Lights;

Authors consider in detail each of the listed sets, the example of which is shown in Figure 2.

The \(Ter\)-set includes a number of surface areas, each of which consists of multiple layers \(Lr\) (to create an overall picture of the landscape representation) and a set of decorations \(Dec\) (to create realistic natural landscape of the production site - trees, grass, etc.).

The \(BSP\)-set is represented by objects of BSP-geometry, which include “filled” and “empty” parts of space. They are described using a set of closed three-dimensional objects composed of disjoint surfaces. This principle of constructing a space is called Constructive Geometry Solid (CGS).

The \(Vol\)-set includes volumes, invisible parts of the virtual space to which various parameters correspond, and which can have different semantic character, for example, they can reflect the area in the space in which motion is impossible or in which actions are supposed to be performed according to various scenarios.

The \(StM\)-set consists of static models of objects that can be moved in space interactively, combined into more complex forms with greater detail (compared to CGS technology). Elements of the \(StM\)-set contain information about the shape of the object (vertex, edges and sides), texture and description of the collision model, which can be conditionally divided into three groups: collision-free, polygonal and simple collisions.

A set of skeletal models \(SkM\) is similar to the \(StM\)-set, however, elements of the \(SkM\)-set can be animated. The position of bones is preliminarily indicated, resulting in an automatic deformation of the external skin of the object (Figure 3). Such an approach allows combining various combinations of the object animation.
The $PS$-set includes elements such as fire, explosions, smoke, water movement, sparks, clouds, fog, snow, dust, hair and others (Figure 4).

Figure 3: Examples of elements of the $SKM$-set

Figure 4: Editor of the Particle System in UDK
The $\textit{AS}$-set is a collection of animation scenes that can be associated with the elements of the $\textit{SkM}$-set for their animation (Figure 5).

The $\textit{TXR}$-set includes a variety of individual textures, for example, wood, metal, fabric, etc., presented in one of the most common graphic formats (png, tga, jpg, bmp).

The $\textit{Mat}$-set consists of a set of different elements, for the creation of which combinations of textures and various parameters (displacement, mixing, etc.) are used. Thus, when creating a material in the UDK, it is possible to achieve the most approximate correspondence of the material image to the real prototype (Figure 6). In addition, it is possible to implement animation of textures.

The $\textit{SC}$-set is formed by a combination of all sound cues. For the sound design of the virtual production space, the sounds of working equipment, the environment, the sound of water, rain, explosions, steps, voice of the announcer, etc. are used.

The set of lights $\textit{Lh}$ is formed by three subsets:

- $\textit{LhP}$ is a subset of PointLights, the light from which is equidistant exponentially in all directions of space;

- $\textit{LhS}$ is a subset of SpotLights, the light from which propagates in one direction under a given radius;

- $\textit{LhD}$ is a subset of DirectionLights, the light from which is similar in characteristics to the sun and can vary according to the time of day.
Figure 6: Material editor in the UDK
Thus, using the Unreal Development Kit as part of the ATS the authors of this article developed a model of workshop, the surrounding buildings, ponds and plantations; the inter-workshop and transport communications were laid; 3D models of equipment located inside the workshop; the background information was presented in the form of pop-up windows (geometric dimensions of equipment, process parameters and others). The examples of models are shown in Figure 7.

![Illustrations of the interactive virtual simulator](image)

The audio feedback of the technological process (sounds of different operating modes of the apparatus, alarms, warning signals) was implemented. In addition to the possibility of moving in a virtual production space, video clips, showing the evacuation routes for personnel in the event of emergency, were created on the basis of the developed 3D model.

The interactive 3D model of the production site, as a component of the AS, is used to train personnel in the basics of the implementation of the process and management of the technical system. It helps to acquire practical skills of working with the object both in the normal operating modes, and in the cases of preventing, localizing and eliminating emergencies. The interactive 3D-environment allows realistic immersion in virtual reality, familiarization with technological equipment, production facilities, accident prevention activities and evacuation plans. The high quality of visualization, the required level of detail, realism of the model increase the level of professional training of personnel and reduce the negative impact of the human factor on the reliability of the technical system.

At the same time, the use of other components of AS – its learning subsystems, virtual and augmented reality – represented by hardware and software opens up new opportunities for customizing the training to the individual needs of the trainee. Using information about psychophysiological features of an individual and the success of previous sessions on the simulator, both the curriculum and the components of 3D visualization can be adjusted. The latter is possible primarily because of the general interactivity of the 3D modeling environment, an example of which we have presented in this article.

CONCLUSIONS

The AIS, described in the article, is intended for training of the CPS personnel, as well as chemical engineering students as part of industrial work placement. Approaches to the classification and use of 3D modeling components in the Unreal Development Kit environment were considered.

The article emphasizes the importance of interactive 3D modeling as one of the main components of the AS, without which it is impossible to ensure the adaptability of the entire system in relation to the individual characteristics of the trainee. 3D modeling remains the central element of the AS visualization subsystem, regardless of the hardware (monitors, helmets of virtual and augmented reality) that authors use in training.

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REFERENCES


