Development of a Visualization System for a Virtual Laboratory for Training Personnel of Industrial Enterprises

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Abstract. An urgent task in the training of personnel of industrial enterprises is the development of the required amount of practical skills. In the context of a pandemic, restrictive measures, as well as the high cost and danger of conducting training on real equipment, virtual laboratories are becoming one of the most promising training tools. The virtual laboratory includes a visualization system (many 3D objects, animations and effects), as well as software components, databases, modules for logging and assessing the quality of exercise performance. Within the framework of this work, the task of developing a visualization system for virtual laboratories is considered. A structural diagram of the visualization system is proposed, illustrating all the necessary elements for creating virtual stands, an implementation algorithm is drawn up. The software implementation is described on the example of a laboratory setup for performing the Reynolds experiments.

1. Introduction
Continuous improvement of technical systems and the possibility of new production situations associated with the maintenance and operation of equipment and requiring effective action by a specialist determine the need for continuous education of employees. Employees can receive a fairly large amount of new knowledge in the professional field in the digital educational space, mastering massive open online courses, or in the process of self-education. A number of professional skills and abilities vital to the personnel of modern production, presuppose their development in the process of professional activity [1].

It is advisable to form part of such skills during training in the workplace, the formation of other necessary abilities involves the use of special tools that simulate a real production process or any situations in production. The possibility of student error in the process of mastering new skills for this kind of activity can lead to emergencies and accidents at work, which makes it difficult or impossible to learn on the job [1, 2].

In the context of a pandemic and restrictive measures, the organization of the educational process in a distance mode has become an urgent task. The specificity of this approach does not allow the training of personnel of industrial enterprises directly in production, contact with equipment, and organize group sessions.
Accordingly, the study of routine and emergency scenarios of activities, physical and chemical phenomena through laboratory and practical exercises can be difficult for a number of reasons [3]:

• distance learning;
• lack of necessary equipment;
• high cost of equipment, materials and other resources for laboratory work;
• student health risk.

The problem of organizing high-quality distance training of specialists can be partially solved by implementing a set of virtual laboratories. Digitalization technologies make it possible to transfer real production processes, to simulate standard and emergency situations. This allows the student to develop the required level of competence formation, including even remotely. This is achieved through the development of visualization systems for virtual laboratories, corresponding to the real working environment. The software of such laboratories can be installed on any personal computer, which allows organizing the learning process even in self-isolation [4].

However, the implementation of virtual labs is not a trivial task. During the development of such systems, the following problems arise:

• adequacy of reproducible physical or chemical processes;
• data logging;
• correct implementation of the training script;
• visual correspondence of the virtual environment to the real world.

Therefore, within the framework of this work, the urgent problem of developing a universal approach to the design of a visualization system for virtual laboratories is considered. This approach should include the general structure of the virtual laboratory, the algorithm for its implementation, and the necessary software tools. The approach will be tested on the example of a virtual laboratory for training industrial personnel and Reynolds' experience in studying hydrodynamic processes. This experiment is considered, for example, in the course of training oil and gas specialists.

2. Review of existing approaches to building virtual facilities

Due to the high demand in the current environment (distance education, restrictions on attendance, quarantine measures, etc.) educational information systems and technologies, which also include virtual laboratory facilities, are gaining more and more popularity. Most often, they are presented in the form of Internet resources or a separate application.

One of the approaches to the creation of virtual laboratories is to use a specific platform that allows you to place three-dimensional models of equipment or facilities, reference material, sound and animate the processes taking place in the real world. An example of such a platform is vAcademia [5]. However, such environments, although they allow you to quickly form educational material and distribute it among students, do not always provide the best visualization quality, functionality and interactivity.

An example of an application is a virtual laboratory developed in the Delphi XE environment and .NET Framework 4.0 for the Federal State Budgetary Educational Institution of Higher Education “National Research Mordovian State University named after NP Ogareva” [6], which consists of three parts for different laboratory work: description, theory, practice. In the practice section, using interaction with two-dimensional graphic objects, you can emulate the operation of real equipment and write the measured data into a table. The disadvantage of this approach is the use of not the most modern and common development environments, which affects the visual component of the application. Virtual simulators of this kind are actively used when three-dimensional visualization of objects or processes is not required, which is especially important for various consoles or flat stands [7].

There are a lot of examples of Internet resources of virtual laboratory facilities, however, most of such resources are created on the basis of outdated technologies and tools, consist of interactive forms, graphic material or models, and interaction with the laboratory is carried out by entering values in certain fields, or using control mouse [8].

However, in recent years, with the development of 3D technologies on the Web (HTML5 and WebGL), the Internet resources of virtual laboratories have increased their quality and have come closer to full-fledged applications [9]. These technologies allow displaying interactive, animated three-
dimensional graphics, animations, moving objects. And although there are also many limitations in this direction, it finds its application for high-quality rendering of high-poly objects.

Thus, some approaches to the development of the visual component of virtual facilities are considered. It should be noted that many existing solutions do not differ in sufficient detail, the quality of the visual component, and cannot be installed on mobile and tablet devices without serious modernization. Therefore, for the implementation of virtual educational tools, it is proposed to use more modern development environments, such as Unity.

3. The structure of the virtual laboratory for performing the Reynolds experiment
Consider the structure of a virtual laboratory facility (Fig. 1), which consists of the following components [10]:

![Figure 1. Block diagram of the virtual laboratory.](image)

- Program code. Implemented on the basis of software. Data and formulas of software for calculations are taken from experiments on a real laboratory setup.
- 3D model of the facility, including pipes, stand frame, water tank and pumping station.
- Animation of hydrodynamic processes (fluid movement).
- A database that stores various modifications of pipes and the rules for their connection, which allows you to ensure the correct connection of pipes to each other.

The listed components make it possible to fully implement virtual facilities and stands of varying degrees of complexity.

4. Algorithm for the implementation of a virtual laboratory
The free development environment Unity was used as a platform for implementing a virtual facility. This software provides all the functionality you need to create 3D and VR-based applications. Unity has a number of advantages: cross-platform, modular component system, visual development environment. These capabilities allow using the finished project on various platforms, which is the most important criterion for expanding the audience of potential users when organizing the educational process [10,11].

The first stage is the creation of the main scene of the project. Scenes are designed to store specific settings, objects, and program code. An application can contain multiple scenes, but the facility in question used one scene, which contains the following objects:

- Main Camera – a camera object that is required to capture and display the scene to the user.
- Direction Light – object of directional light. Since the main object is a 3D model of the virtual facility, the stage must be illuminated so that all parts of the facility are clearly visible to the user.
- Station Spot – an object on the stage, which is the location of the virtual station when it is initialized.
• Start – an object that contains the initialization script for the entire project. This script is launched when the program is opened.
• Canvas – an object in Unity containing the class of the same name. This object is required to work with the interfaces of programs developed in this environment. Here you create, configure and store interface elements, as well as configure the scaling of elements for different screen resolutions.
• Particle System – a component that simulates liquid substances like different liquids, clouds by generating and animating a large number of small 2D images in the scene. Prefabs (objects intended for repeated use) are also placed on the stage. The main prefab of the scene contains a 3D model of the setup and a script that implements the functioning and interaction of the elements of the experimental setup [12,13].

For the functioning of the interface elements, a script has been created that is tied to the Canvas object. This class stores references to all elements of the program interface and to the actions that they can perform. A script is also attached to the Start object that initializes copies of the facility prefabs. This script stores links to the original prefabs, the Stantion Spot object for placing the created copy of the stand, the scene camera. To replace the stand, you will need to replace the original template with a new prefab. Then, when the program starts, a copy of the new facility will be initialized.

Also, for the implementation of various options for laboratory work, a designer has been developed for connecting various options for pipes, which allows the user to set different routes for the movement of liquid. For each option, pipe roughness, fluid velocity and other parameters can be set [14].

Thus, to implement the constructor, it is necessary to develop a database and rules for connecting pipes to each other. The structure of the database is shown in Figure 2.

The database is further integrated into the virtual laboratory and is used at the stage of designing the pipe connection scheme (selection of various modifications of pipes, checking the conditions of their connection) [15].

The last stage in the implementation of the virtual laboratory is the calculation of the output parameters of the facility based on the given input variables. For each facility, the set of such parameters and variables is unique and is set by software (based on analytical equations or experimental data) [16].

5. Software implementation of the Reynolds experiment virtual setup system

The virtual laboratory is designed to perform Reynolds experiments, the essence of which is to observe the flow regimes of liquids. Reynolds carried out his experiments on an facility, which is a tank of water, to which an outlet glass tube with a faucet at the end was attached to the bottom. The tank was constantly filled with water, and the water consumption was measured using a measuring tank and a stopwatch. Above the tank was a vessel with paint, which fell into the water through a thin tube with a tap [17]. Let's look at two key experiences for this setup.
First experience. The tap at the outlet of the tank was slightly opened, and water began to move in the tube at a low speed. When paint was added, a sharply defined colored trickle appeared in the outlet tube, which did not mix with the rest of the water. A laminar flow regime was recorded.

Second experience. With further opening of the tap and an increase in the flow rate, the trickle of paint began to bend, turned into separate vortices and mixed with the rest of the water. The transition of the laminar regime to the turbulent one was observed.

The input variables of the virtual facility are:
- pipeline diameter;
- average flow rate;
- fluid density;
- dynamic fluid viscosity.

The output parameter of the setup is the Reynolds value Re, which determines the fluid flow regime [18]. Examples of values for smooth pipes:
- laminar: meaning Re < 2100;
- transient: meaning 2100 < Re < 2300;
- turbulent: meaning Re > 2300.

Thus, the software obtained on the basis of experimental data implements the mapping of a set of input variables to output parameters. This allows you to obtain correct values during laboratory work on the entire range of input variables with sufficient accuracy due to the implementation [19].

Externally, the virtual setup differs from the setup used by Reynolds (Figure 3, 4). It has an electric pump that ensures the flow of water at a certain pressure. It also implements a database that contains various modifications of pipes, the bends and roughness of which are taken into account in the mathematical calculations of the results. All of these elements allow you to complete both experiences without difficulty and without losing any data [20, 21].

**Figure 3.** Visualization of laminar fluid flow.

**Figure 4.** Visualization of turbulent fluid flow.
The implemented virtual laboratory allows training specialists to study hydrodynamic processes using the example of Reynolds' experience. The presented approach to the development of virtual laboratories, the developed structure and a set of software tools are universal and allow the implementation of facilities of various types [22, 23].

6. Conclusion
Visualization of laboratory facilities and stands is one of the progressive directions in the development of teaching methods. The development of such products is an urgent and important task in various areas of training specialists, since the quality and effectiveness of training depends on them [21].

The virtualization of entire laboratories reduces the cost of purchasing laboratory equipment, increases the number of work benches, which makes it possible to train more specialists who, in a short time, will be able to familiarize themselves with the principle of work and acquire the necessary skills for interacting with facilities.

This article looked at an approach to developing a virtual laboratory. The structure of the software implementation of the stand is presented, including the tools used. The described approaches are suitable for use in the development of various types of virtual laboratories and stands.

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