SCADA Systems and Augmented Reality as Technologies for Interactive and Distance Learning

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Abstract. This paper discusses the use of SCADA systems for creating virtual laboratories for technical and natural sciences. Electronic interactive training material, virtual laboratory work and testing systems have been designed in a unified environment. The authors have established the features of the learning context for virtual laboratory work in the university course of physics as a case study. The paper also considers the capabilities of augmented reality applications in laboratory classes.

Keywords. Virtual laboratory work, SCADA system, interactive and distance learning
Key Terms. ICT Tool, Virtual Laboratory

1 Introduction

Active introduction of computer-aided learning tools into the process of student training greatly contributes to the quality of education and specialist training. Mass open online courses are one of the most promising trends in the development of education. Formally, they are e-learning courses including video lectures, lecture text notes, interactive exercises and tests for students. The most popular international educational platforms are Coursera, MIT Open CourseWare, Edx, Udacity, Prometheus, etc. To check the knowledge acquired by students, teachers can use a variety of interactive exercises such as answering closed and open questions, solving mathematical and chemical equations, and the program code checking on the server. For this purpose, the courses must include the Rich-media content such as Flash, Java, and others.

At that, numerous universities face a number of factors that should be taken into account for engineering disciplines in systems of interactive and distance learning, namely:

- laboratory work requires significant time that in the majority of cases is quite difficult to integrate into the system of interactive and distance learning;

- students should be taught real practical skills, similar to those they will acquire carrying out traditional laboratory experiments;
- cost of laboratory equipment makes it impossible to provide every student with a complete set of required tools.

The vast majority of educational platforms focuses primarily on the visual presentation of training materials, but does not provide students with real practical skills. At the same time it is important to enable students to participate immediately in the process, to conduct laboratory experiments using the equipment and analyze the results obtained.

To solve this problem one must create computer models of laboratory facilities and use them in interactive learning software package. These models are used to build virtual computer laboratory workshops, simulators and training facilities. Of particular importance is the use of virtual laboratories in the study of engineering and scientific disciplines [1-3], e.g. physics.

Virtual laboratories in educational process are used as computer simulators for training students to carry out practical part of research as in real laboratories. Alternatively, they can be used by students to get additional real practice i.e. carry out computer experiments that for various technical, financial, organizational and other reasons cannot be performed using physical hardware. The model is supposed to include all major parameters of real equipment, phenomenon or process under study. In addition, the control units of gauges and other laboratory equipment are to be foreseen and function properly. Another approach can be employed when students themselves become “designers” and build models of laboratory equipment using a set of standard component. When using virtual models students get more opportunities for research and creative activities. Thus, virtual models help students to better learn the training material [4-6]. However, it should be noted that virtual models have to be properly worked out in detail. Here are some of the benefits of virtual laboratories. They help to avoid the difficulties associated with the production of physical experiment. Every student performs an individual experiment (the initial parameters can be alternated practically ad lib). Students confirm the automated calculation "manually" that allows them to understand the basic principles of algorithms and techniques used for software design (the software is not treated as an abstract black box). Students are motivated to do research (analyze a number of experiments, build dependencies and compare the results obtained).

The use of virtual laboratory work as a computer simulator enable students to be better prepared for conduction of physical experiments, to get a deep understanding of the phenomena and processes under study, and to acquire skills of operating the gauges (in cases when virtual laboratory work include computer models of gauges similar to the real ones by their parameters).

2 Virtual Laboratory Development Framework Review

Virtual laboratories can be designed by means of various frameworks and technologies, most of which are associated with building of Rich-media content. The range of modern software technologies that deliver Rich Internet Application (RIA) can be used to develop a virtual laboratory based on the Adobe tools and web technologies (Shockwave, Flash, Apache Flex, Air, Gaming), Java (Applets, JavaFX), Microsoft (Silverlight / Moonlight), Google (Native Client), as well as HTML5 and JavaScript.

1. Adobe Tools and Technology. Basically, Adobe Shockwave and Flash are the most popular technologies used to build virtual laboratories. These frameworks manipulate raster, vector and 3D-graphics, process audio and video content and create animated and interactive images. As media platforms they can create interactive game tasks and provide e-learning courses, demos and other cross-platform content. The development of virtual laboratory work in the teaching of engineering and natural science disciplines is supposed to be supported by graphic acceleration.

For this purpose NVIDIA PhysX is widely adopted to simulate real interaction between the bodies and the action of gravity and other forces. The examples of virtual laboratory work using these technologies for teaching engineering and science disciplines are given in [1,7-8]. It should be noted that recently Adobe Systems has terminated the support for Flash Player on GNU / Linux-based operating systems and mobile platforms in favour of HTML5. Google also actively contributes to the complete replacement of Flash by HTML5. It has released a free Google Web Designer application aimed to help designers and programmers. Besides, popular browsers have announced the termination of support for flash technology in the nearest future. As a result, a great number of educational resources hurry to replace their flash animation with modern HTML5 code.

2. Java Technology. If Java-related technologies are used there is almost no limit to the implementation of both conventional (illustrated theoretical background of the courses) and active on-line control and training systems. Java enables the creation of a single integrated automated educational environment. To create virtual laboratories one can use Java Applets and JavaFX, which are prevalent in real applications used for the engineering and scientific disciplines [9-12].

3. Microsoft Technologies. Microsoft Silverlight is a powerful software platform that incorporates multimedia, graphics, animations and interactivity. Unlike Flash / Flex, Silverlight supports more powerful .NET languages. In addition, to create animation Silverlight uses time intervals that are simple, convenient, easily adjustable by both XAML and in the code, and are not frame-based (as Flash / Flex are), so every animation lives its own life.

Silverlight is more convenient for making controls, whereas Flash / Flex are inferior for this purpose. Finally, Silverlight is based on a full multi-threading model. In spite of the considerable advantages, there are few virtual laboratories designed using Silverlight [13].

4. Google Native Client (NaCL). It should be noted that Google has not marketed its Native Client technology as a platform for RIA, however it can be formally considered to be the one. Unlike JavaFX or Silverlight, this technology is not transformed into bytecode or any other code format by a compiler. In general, this technology incorporates a container acting as a "sandbox", the runtime for native code and a plug-in for the web browser (Google Chrome 14 or greater has Native Client built-in).

However, NaCL is not considered very powerful for creation of interactive applications in this context, and preference should be given to API HTML5.

5. HTML5. This is a standardized technology with rich multimedia content and interactivity. One of the key options HTML5 offers is the creation of 3D graphics directly on a web page, using the Canvas API. At the same time HTML5 is not a tool for the development of content, design, video, animation, and interaction with the user. For these purposes a combination of HTML5, CSS3 and JavaScript is used. It should also be noted that all RIAs have fundamental weak points, determined by their architectures. First, one of the weak points is the need to load / install additional software, including RIA plug-in itself and the scripts it executes. A second, more serious problem is that RIA-engine is an environment foreign to the browser, often opaque and inaccessible from scenario. In this regard, HTML5 is able to provide a clear single runtime environment, with available components. Examples of HTML5-based virtual laboratories, developed using HTML5 can be found here [7, 11].

6. JavaScript. JavaScript is used to create interactive web applications. At the moment, there is a great number of extra libraries and frameworks that can be used to create virtual laboratories such as jQuery (interaction with the DOM elements, event handling, etc.), MathJax (formulae display), Three.js (creation and display of interactive, animated computer 3D graphics by means of WebGL), Chart.js or D3 (data visualization, charting, etc.) and many others.

7. Modeling systems. Of particular interest is AnyLogic as a multimethod simulation modeling tool developed by The AnyLogic Company (former XJ Technologies). It supports multiagent-based, discrete event, and system dynamics simulation methodologies. AnyLogic allows users to build visual and hierarchical models. Graphical modeling language (UML-RT-based) operates the concept of active objects and relationships between them that can be discrete (sending messages of any structure) and continuous (monitoring the indicators). The advantages of this tool environment include the ability to describe complex systems with a dynamic structure and change the parameters of the model during the simulation process. To describe complex behaviour the user can use graphic statechart diagrams. The behavior of objects is described using code fragments in Java. The user has to determine the essential action code in the fields of special properties of object elements, whereas the entire routine code is auto-generated. The system gives users great opportunities in creation of virtual test benches to manipulate models with controls, graphics, and two-dimensional and three-dimensional animation. Virtual laboratory work can be also created using specialized domain-specific software packages. They include Electronics Workbench system and NI Multisim that have been created for simulation of electronic circuits, and ChemOffice designed by CambridgeSoft to simulate and analyze chemical processes.

8. Automated systems for research. The MATLAB platform supports mathematical computations, visualization of scientific graphics and programming. MATLAB comes with the expansion package Simulink, intended for the simulation of dynamic systems whose models are made up of individual blocks. This package uses the principles of visually-oriented programming, which makes it easy to gain the necessary blocks and connect them to system models or device models. The graphical interface of virtual laboratories is created with MATLAB tools [14]. LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is an integrated system designed for computer-aided design of laboratory experiments. The system is used to computerize laboratory tests, collect and measure the data, integrate the operation of equipment according to various protocols, and enable graphical programming, besides it has powerful mathematical support. The system comprises an extensive library of elements required for the development of virtual interfaces of physical devices and laboratory equipment. The LabView software was used to create virtual laboratory work by the Spanish University of Distance Learning [15], the Massachusetts Institute of Technology [16] and many others.

Thus, a range of modern programming technologies used to create RIA-applications allows developing of virtual laboratory work based on Flash, Java, HTML5, JavaScript, and others. However, even if ready-made frameworks and libraries are used, these technologies cannot be counted as universal tools for quick creation of virtual laboratory work or similar applications available to a wide public rather than just to programmers. On the other hand, visual modeling systems can solve this problem, but there is not such a single system that can ensure integrated automated educational environment.

3 Development of Virtual Laboratory based on SCADA System

The staff of National Aerospace University «KhAI» has used industrial control systems, namely SCADA systems as a technique for creation of virtual laboratories. SCADA (Supervisory Control and Data Acquisition) deploys multiple software and hardware elements that allow industrial organizations to develop and launch distributed process control systems in real time. The SCADA technology provides a high level of automation in solving the problems of control system development, collection, processing, transmission, storage and display of data. SCADA systems have smart graphical tools for creating software and dynamicized screens that are responsible for real-time monitoring of the systems and processes. SCADA-based virtual laboratories can display the experiment or process more accurately through the use of a mathematical model that provides a full description of the system. In addition, the use of this technology for KhAI saves time and improves the quality of the design process.

The virtual laboratory has been designed to help learners study university physics including such courses as Mechanics, Thermodynamics, Molecular Physics, Wave and Quantum Optics, Electricity and Magnetism. It should be mentioned, however, that the laboratory equipment has not been used yet for studying the required branches of physics, but it is actively developed and expected to be put into action in the future.

The virtual laboratory has been created using SCADA Trace Mode by AdAstra Research Group. SCADA Trace Mode is a high-tech software platform that enables the design of interactive electronic training material, virtual laboratory work and testing system in a single environment.

SCADA Trace Mode is free and user-friendly software platform that does not require any special knowledge and skills in programming and can be well used by the university teachers. The labs have been composed according to a prefabricated pattern including all the necessary basic screens and programs for further adjustment and content integration. This approach together with the high functionality of the software allows creating of an interactive course within a shorter time period.

The project of the virtual laboratory consists of interrelated parts with clearly distributed functions. The laboratory work is performed on a staged basis. The project of a virtual laboratory includes the following stages: Selection of Physical Laboratory; Authorization; Choice of Particular Laboratory Work; Introduction to Interactive Screens with Theoretical Background; Facility Description and Laboratory Methods; Answering Questions for Admission to Laboratory Work Execution; Operations with Virtual Laboratory Facilities and Experimentation; Answering Test Questions and Performing Laboratory Exercises; Assessment and Recommendations.

The virtual laboratory has been developed using SCADA-system Trace Mode and included creating a project structure (each part has been assigned a laboratory and of a set particular work tasks to be done), a resource library (images, graphics and video files, etc.), an information structure of the project (general and specific channels for each mathematical model), graphics screen templates, program patterns, as well as binding of attributes and channels to the programs and screens, and setting of interaction with an external database to record the statistics of trial runs and successfully completed labs.

SCADA Trace Mode ensures a very simple development procedure due to the object-oriented approach and use of templates. It supports multiple programming languages, including visual languages and other advanced graphics etc. This approach allows the users to create virtual laboratory projects with flexible and scalable object structures where any component e.g. a variable, a screen, an algorithm or a SQL-query can be used any number of times when completing any laboratory work.

The procedures of the virtual laboratory work development are described below.

4 A Virtual Laboratory of Physics in the KhAI

The first part is Theoretical Background. It presents a brief theoretical description of the phenomenon or process under study and offers the required formulae. The scope of the text information shown on the correspondent screens is kept to a minimum, however, it is sufficient for the students to understand and learn the material presented (see Fig. 1).

Illustrative material is an inherent part of Theoretical Background. It includes the examples illustrating how the studied phenomenon or process occurs or runs in engineering and in everyday life. This material contains visual multimedia information and clear interactive elements to demonstrate the processes and phenomena under study. The multimedia information and interactive elements show the features of the phenomenon, process or the experiment itself that are difficult to imagine or cannot be observed otherwise than in the virtual laboratory. The animated and interactive elements allow the user to see not only a static image of any physical phenomenon, but also to take a look at it in real-time mode on the basis of the developed model. The Theoretical Background part also includes interactive tasks or training exercises to be done.

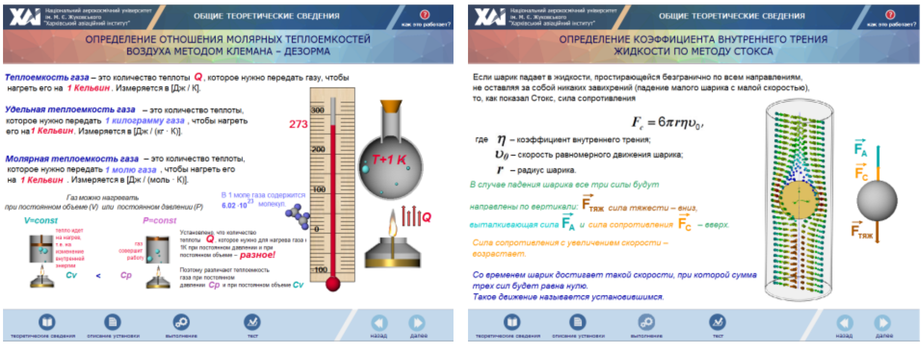

Fig. 1. Theoretical Background displayed on screens for labs in Thermodynamics

The Facility Description part presents an interactive diagram of the experimental facility or equipment and describes its functions (see Fig. 2). The interactive elements give an image of the parts of the facility or equipment and show how it operates.

Fig. 2. Facility Description displayed on screens for labs in Thermodynamics

The environment allows creating of three-dimensional models of real objects. The student has an opportunity to learn the facility/equipment, the devices and the studied object interactively, in the same way as if he/she had seen them in reality.

Also provided is a list of measuring instruments whose operation is simulated in a realistic way. The authors of the project have carefully worked out this component of the laboratory work, because it is essential that the students be able to learn how to measure the objects and handle the measuring devices and instruments (see Fig. 3).
The part also includes performance of interactive tasks, drill on assembly of the equipment, the switch-on sequence and experiments with laboratory facilities and measuring of the process parameters. Here, the actions and techniques realistically

simulate what happens in a real laboratory. If something goes wrong, the student will have to start the operation over. Every component has been carefully selected, enabling the accurate measuring operations and other specific techniques. After the measurements are done, the laboratory complex allows the student to check the correctness of the task performed.

The Laboratory Methods contains guidelines on how to conduct the experiment, collect and process the data. The interactive elements provide students with the opportunity to learn how to conduct experiments. This stage is one of the most important because the authors of the project have to carefully choose the activities to be done, specify the things to be observed (problem descriptions) and the conclusions to be made by the students within every specific laboratory work. For example, the student may have to weigh and measure the required volume, to observe how the process runs, to record its parameters and make conclusions about its properties, etc.

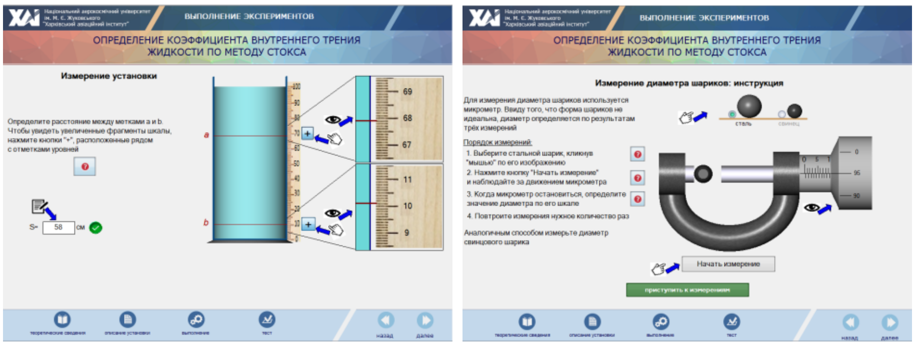

Fig. 3. Measurements with specific instruments and devices

The Admission part is provided to check the student's readiness for experiment conduction. Here the student has to answer the questions in the test and do some interactive tasks (see Fig. 4).

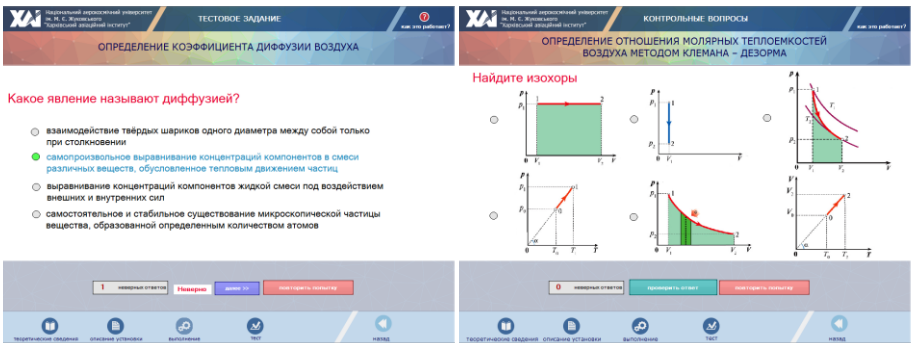

Fig. 4. Admission tests and tasks allowing the student to conduct the laboratory work

The environment let the authors create colorful and comprehensible tests with illustrations, tables, diagrams and formulae. Various types of testing have been included: tests with open and closed questions, time-limit tests with a predetermined sequence of questions, tests with an arbitrary sequence of questions etc.

In the Operations part the student work with a virtual model of laboratory facility to conduct the necessary experiments (see Fig. 5). The progress check has been introduced for individual stages of experiment, virtual measurement input and formula calculations. The results of the experiment or computer simulation are recorded in the form of specific values of magnitudes, graphs, tables and charts.

Fig. 5. Laboratory work operations

In this part the main emphasis is made on high feasibility of the experiments, the accurate simulation of physical laws of the world and the nature of experiments and phenomena, as well as uniquely high interactivity. It is necessary to reproduce the real interface of the facility or device in the form of a virtual model, keeping all its functions active. As a result, the student will get the impression that he has been working with real instruments and equipment. Depending on its goals and objectives the laboratory work may include several experiments or several series of experiments. It should be borne in mind that in the virtual space, the experiment can be performed much faster than in a real lab, that is why model time scale can be changed.

The SCADA technology makes it possible to conduct the experiment in a real laboratory with industrial equipment by means of remote access to the object under study. In this case, experiments are carried out in a real time mode using the laboratory facility. Students can set the performance characteristics, activate/inactivate the appropriate instruments, read the data from the controlled devices and store them on their computers in order to process later. The objectives of laboratory work have been determined taking into account the expected results: students must acquire practical skills of operating the measuring instruments and tools, learn how to conduct experiments, make particular conclusions based on the results of the experiments, understand why they have obtained particular parameters, regularities and effects. The Progress Check part contains test questions and interactive tasks to check how the student conducts the experiment.

The Assessment and Recommendations part is intended to assess the laboratory work done by the student, based on the number of errors made during the admission test, experiment conduction and progress check. The assessment decision is used to make recommendations regarding the progress and quality of the learning process, as well as further activities for the student (Fig. 6). While performing the laboratory work, the student is helped by a virtual assistant that performs intelligent functions of the system and some mechanisms of adaptive learning.

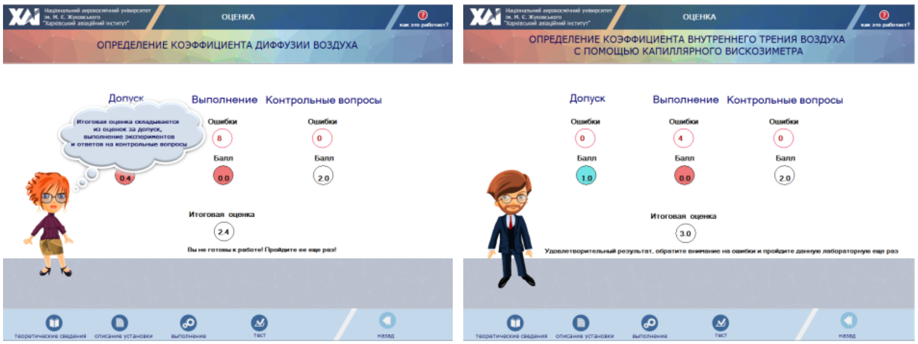

Fig. 6. Assessment and Recommendations

The developed virtual labs are used to consolidate the knowledge and skills of students doing both the classroom and independent work. Despite the advantages of virtual laboratories, of course, one cannot underestimate the value of real laboratory work. Virtual laboratory work helps to prepare students for carrying out real laboratory work. First of all, by performing virtual laboratory work students learn to solve research and computing tasks within on some scientific topic. Secondly, they learn the methods and techniques of the experiment conduction. Thirdly, they learn the laws of physical processes through the active participation in the learning process.

When developing models, the authors have assessed and analyzed the reliability of the process and the results of virtual experiments compared to the real ones. During the experiment, the students were divided into two groups. Both groups of students had the same pre-tests, which showed no statistically-significant differences between the measurements. The first group performed the laboratory work using real equipment, the second group worked with virtual equipment. To estimate if there are any significant differences between the mean scores we have conducted two simple tests for independent participants. The differences between the test results have proved to be statistically insignificant. The results are shown in Table 1.

Table 1. Comparison of virtual and real lab scores and test resuts

Group	N	Pre-Test (Mean±S.D.)	Post-Test (Mean±S.D.)
Group#1 (Real)	34	3.79±0.84	4.0±0.78
Group#2 (Virtual)	42	3.83±0.82	4.05±0.83
t (df = 69.983)		-0,203	-0,528
p-value		0,839	0,797

5 The Use of Augmented Reality Technologies in Laboratories

In parallel, the authors work out augmented reality applications to improve virtual laboratory work. Augmented Reality (AR) is a synthesis of virtual and real worlds, when additional information or imaginary objects are overlaid on the real-world images. The use of augmented reality in education makes it is possible to visually reproduce the processes that are difficult or almost impossible to reproduce in the real world or just to make the learning process more entertaining and comprehensible.

At the moment there are a number of technologies to generate augmented reality. In the augmented reality a special device scans the space around and creates its digital model in real time. For this purpose, marker-free detection is used. It is based on detection algorithms according to which a virtual “frame” is superimposed on the surrounding scene caught by the camera. The software algorithms analyze this “frame”, finding the reference points (markers) and according to the position of each marker in space, the program can accurately project a virtual object onto the scene. This will help to achieve the effect of its physical presence in the surrounding environment. Marker detection uses markers that are the surfaces with specific images to which digital content is merged (Fig. 7). Thus, augmented reality markers are various stands and laboratory facilities. Students can use their tablets or phones to get a three-dimensional image and video information about the studied processes and phenomena, facilities and their parts as well as the tasks to be done etc.

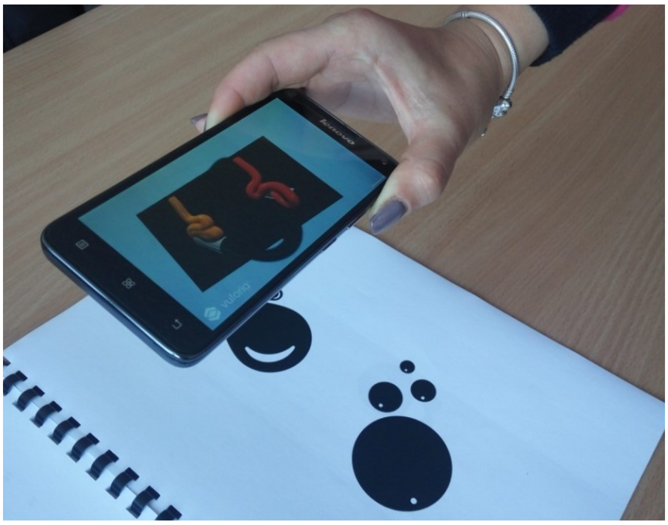

Fig. 7. Augmented reality in a real laboratory

6 Conclusions

Thus, National Aerospace University “KhAI” has developed a SCADA-based virtual laboratory to teach physics to the students. The advantage of this approach is that a single software environment has been used to create electronic interactive training material, virtual labs and testing systems. Thus, the students have an opportunity to perform virtual laboratory work using hardware both in the classroom and independently through a remote access. The time required to perform laboratory work using real layouts and instruments is reduced for similar virtual laboratory work. The virtual laboratory allows the students to repeat the experiments setting different conditions, making errors with no negative effects. The virtual laboratory work is a powerful, flexible and easy-to-learn tool that teachers of engineering and science disciplines can use to train students in an interactive form, with a possibility of independent experiment conduction. The technology of virtual laboratory work greatly contributes to and promotes professional skills of students.

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