Using Virtual Reality Technology for Studying Physics

Yevgeniya Daineko(✉), Madina Ipalakova, Dana Tsoy, Zhandos Baurzhan, and Yersultanbek Yelgondy

International Information Technology University, Manas str. 34/1, Almaty, Kazakhstan
yevgeniyadaineko@gmail.com, m.ipalakova@gmail.com, danatsoy@gmail.com, zhandos.baurzhan@gmail.com, ersultan_elgondin@mail.ru

Abstract. The field of education is relatively conservative, but at the same time fast evolving sphere of human activity all around the world and in Kazakhstan as well. This is due to constant advances in all technology areas and in information technology in particular. New teaching and learning approaches, methods and techniques are introduced into the educational process, applying various technologies like artificial intelligence, computer vision, robotics, etc. And virtual reality is one of those. Virtual laboratories are one of the computer-based learning systems that can help to study various processes (physical, chemical, etc.) simulating and visualizing them on a personal computer without using the actual equipment or reagents. Moreover, with the help of such simulations it is possible to observe the process in detail, from different points or enlarge the image to a convenient size. In this paper an application that helps to study physics in secondary schools is presented. It contains a set of practical problem tasks from a number of physics sections. Each task has visualization scene with virtual reality integrated. In the article the content, architecture and interface of the application are presented along with the short review of other research in the field of application of virtual reality in education.

Keywords: Virtual reality · Education · Physics · Virtual experiments

1 Introduction

The introduction of new information technologies along with the computerization of educational institutions and the innovative activities of the academic staff are the main directions of the comprehensive modernization of education, to which the special attention is paid not only throughout the world, but in Kazakhstan as well [1–4]. As an example of this process implementation the state program "Digital Kazakhstan" can be taken, developed by the government of the Republic. One of the goals of this program is to increase the digital literacy of the population, including on secondary, higher, technical and professional levels of education, as well as within staff and professional development courses. Currently we can witness the world trend – Industry 4.0 which implies a massive introduction of cyber-physical systems, such as artificial intelligent, virtual and augmented reality, quantum computing, 3D printing, autonomous robots in

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production and everyday life, including education. The latter is also heavily influenced by information technology including not only the computerization of business processes of secondary and higher educational institutions, but introduction of new methodology and learning tools based on the modern technologies. In the latter field the computer learning systems like virtual laboratories are prominent. They allow conducting experiments without real equipment and all the processes are simulated by a computer [5, 6].

Currently, students' perceptions can be improved with the help of new visualization elements and gestures offered by modern digital technologies. In particular, with the virtual reality technology (VR – Virtual Reality), new ways of learning are coming to the fore, which make it possible to reveal the student's interest in the subject being studied, stimulate positive emotions, accelerate the learning process and help to better understand the topic. VR introduces the game principle into the learning process, which certainly has a positive effect on the students' performance.

In this article the software with a set of practical tasks and animations with virtual reality embedded for studying physics in secondary educational institutions is presented. The application is developed in the International Information Technology University (Almaty, Kazakhstan).

2 Related Works in the Field of Development and Introduction of Computer Learning Systems Based on the Virtual Reality

The level of application of various technological tools grows rapidly in all the fields of human activity and in education as well. In the past we used pen, pencils and books and now interactive technologies are available to help to deliver knowledge and understanding. In the recent years we can observe how deeply digital technologies have penetrated our lives.

Thus, in [7] the virtual environment is presented that helps students to study the tourism development issues and related impacts. VR is used to fully immerse students in the environment. The current approach is useful to provide participants with a holistic experience of real environment, which in reality is expensive, especially for groups with a large number of people. The pedagogical value is achieved through immersion in an environment based on reality, interaction with complex and ambiguous situations and information, as well as interaction with space, other students and teachers. The results demonstrate that such complex virtual learning environments can be developed, and the main problem is a high level of interactivity.

The study of algebra is accompanied by frequent problems for both students and teachers. In [8], an example of studying algebra with the help of virtual reality. The authors have developed an open educational resource Virtual Algebra Tiles, which enables students to expand their knowledge on algebra concepts using a computer. The research results showed that such a learning system for students is comfortable, and therefore the learning process becomes a more pleasant task.

In [9], a study was conducted on how gifted students perceive virtual programs. Students were enrolled in a virtual course. Data was collected through asynchronous focus groups on an interactive discussion board, using observations of synchronized activities in their virtual classroom, as well as individual interviews with participants. Studies have shown that some technical difficulties have arisen, mainly due to operator errors or non-use of available tools. From the point of view of the curriculum and pedagogy, the participants saw a slight difference between the classical and virtual classrooms. And it can be concluded that for gifted students, the quality of content and learning is more important than the reality of learning environments (virtual or actual). This information can be used further to improve the quality of on-line education or to create new software.

The article [10] is aimed at studying the perceptions of teachers regarding the introduction of virtual reality to educational process with the help of a case study in the Faculty of Information Technology (IT) at a university in the Middle East. The respondents interviewed for this study were teachers. A quantitative method was used: an adapted questionnaire was distributed among IT teachers on the Internet, which assessed their opinion on the possibility of using virtual reality as a training tool. Statistical data was used to analyze the questionnaire data. The results obtained on the basis of quantitative data revealed the willingness of teachers to use VR systems as an additional teaching tool, their intention to include them in the educational process in the future, barriers to the use of technology, and prerequisites for users. The results also showed that learning can be as effective as possible with the integration of VR technology. The article also provides recommendations for facilitating the use of VR technology as a learning tool.

A specially designed and tested virtual reality learning environment [11] can offer medical students access to educational materials and their re-learning, thus improving educational process. In addition, the use of such training tools will make medical education more accessible. The article also shows that virtual reality has a unique potential for the transformation of medical education and offers an increase in investment in technology development and the possibility of cooperation with developers.

The work [12] discusses the use of virtual reality technology to gain knowledge about evacuation, which is a key to reducing injuries and increasing survival. Serious games (SGs) based on immersion virtual reality represent an innovative approach to training and educating people in the gaming environment. This article aims to understand the development and implementation of such serious games in the context of training and research in the field of evacuation of buildings applied to various emergency situations in them, such as fire and earthquake.

In [13], the effectiveness of using immersive virtual reality for learning the effects of climate change, in particular for studying the acidity of sea water, was discussed. Studies have shown that after the experience of immersion in virtual reality, people showed a good level of knowledge, curiosity in the field of climate science, and in some cases showed a more positive attitude to the environment. The analysis also showed that immersive virtual reality is a promising additional mechanism for effective learning, since the more people explored the spatial learning environment, the more they demonstrated a high level of knowledge about environmental change.

In [14], the use of virtual reality technology to study architecture is considered. Due to its empirical nature, VR technology can be very effective in obtaining architectural education. The authors developed the LADUVR application, which users can use on the construction site to study the architectural details more closely and check what they have learned in an interactive and exciting environment. The article also presents a comparison between traditional teaching methods and the use of virtual reality technology.

The use of virtual reality technology in museums is also relevant. It allows presenting information in a more visual, interesting and memorable form, as well as attracting more visitors. The work [15] presents guidance on the development of educational games in collaboration with the museum. The authors showed that mini-educational games using virtual reality technology considerably help students in the study of artistic concepts.

In such a way, it can be concluded that the virtual reality is widely used in education for in-depth study of various courses.

3 Software Support of the Project

In this project, for the development of software, a cross-platform computer game development environment is used, the game engine Unity 3D from Unity Technologies [16]. It allows creating virtual reality applications running on personal computers, mobile devices with iOS and Android operating systems, or Web-based applications. This in turn makes applications widely available. Other benefits of Unity are:

- visual development environment, which includes not only visual modeling tools, but also an integrated environment, an assembly chain, which is aimed at increasing the productivity of developers, in particular, during the stages of prototyping and testing;
- highly qualified technical support;
- a variety of methods for manipulating physical objects, which facilitates visualization of physical processes.

Virtual reality implies a simulation in which a virtual, but realistic world is created using computer graphics. Moreover, the reproduced world is not static, but responds to the user's incoming flow (gestures, verbal commands, etc.) [17].

As a virtual reality device, the Leap Motion Controller contactless control device [18] is used, which is based on motion capture technology. To capture the projection of user's hands in space, the Leap Motion device uses two optical sensors (cameras) and an infrared light source. After connecting the device, a virtual inverted pyramid with a central vertex in the device is formed above it. The most effective range is from 25 to 600 mm above the controller with a field of view of 150°. In the area of this pyramid, Leap Motion "sees" all movements and sends them to software that converts data and signals into coordinates and messages. The software is able to recognize both simple gestures (virtual touches, clicks), and complex continuous movements: scaling, moving, rotating, and drawing various geometric shapes.

The Leap Motion Controller was chosen for the following reasons:

- Unity 3D support;
- works on mobile processors with low latency and high precision;
- hands are initialized faster and tracked better on difficult backgrounds and extreme lighting conditions.

4 Results

As a result of the project in the International Information Technology University (Almaty, Kazakhstan), a software application with a set of practical tasks and animations with virtual reality to study physics in secondary schools was developed. This application can be used not only in Kazakhstan, but also abroad, as the application menu is implemented in three languages: Kazakh, Russian and English.

The developed application gives an access to a set of physical problems from such sections of physics as kinematics, basic dynamics, static elements, conservation laws in mechanics, mechanical vibrations and waves, molecular physics and thermodynamics. Each task is implemented as a separate module, which provides a 3D visualization of the physical process studied within the problem. The interaction with the application as a whole, as well as with the visualization is realized using the Leap Motion controller.

The practical tasks were chosen in conjunction with the physics teacher from the Republican Physics and Mathematics School (Almaty, Kazakhstan). First, the topics for the tasks were selected according to the school program of the physics course. Second, the level of difficulty of the selected tasks is medium and high; the choice was made in favor of those tasks, for which additional visualization of the studied process is important in order to gain a deeper understanding and mastering of the material.

One of the distinguishing features of the presented application is that it is multilingual. The user can choose Kazakh, Russian or English language of interaction with the application. Figure 1 shows the main application menu with the Leap Motion controller integrated into it.

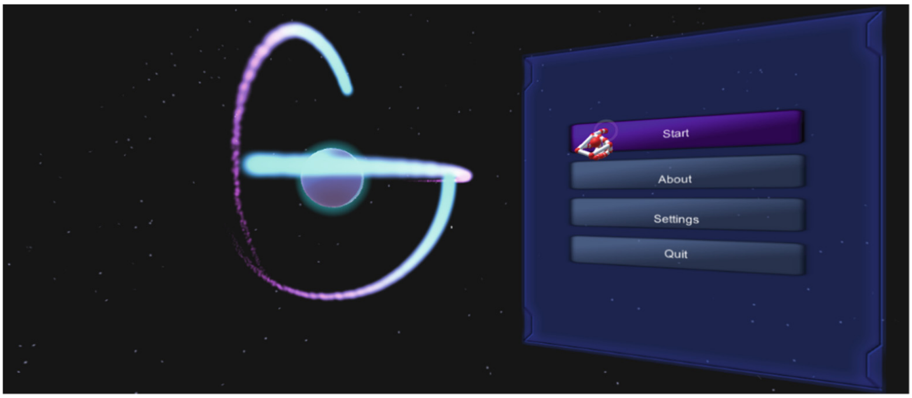
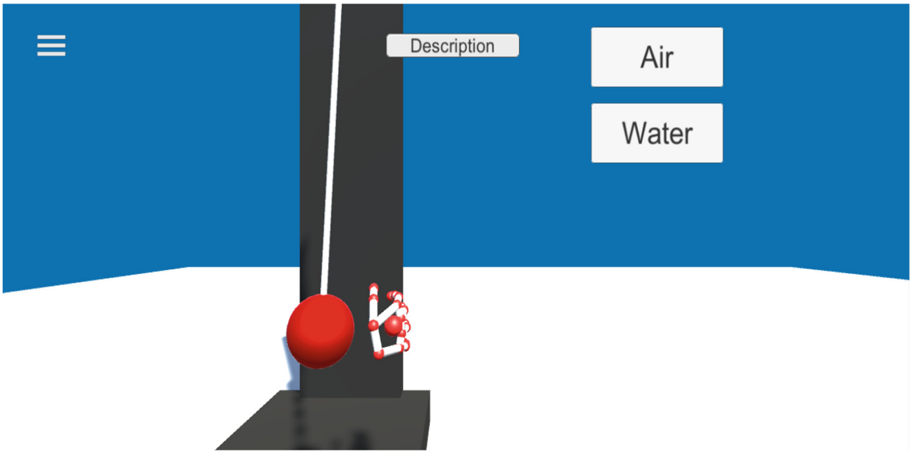
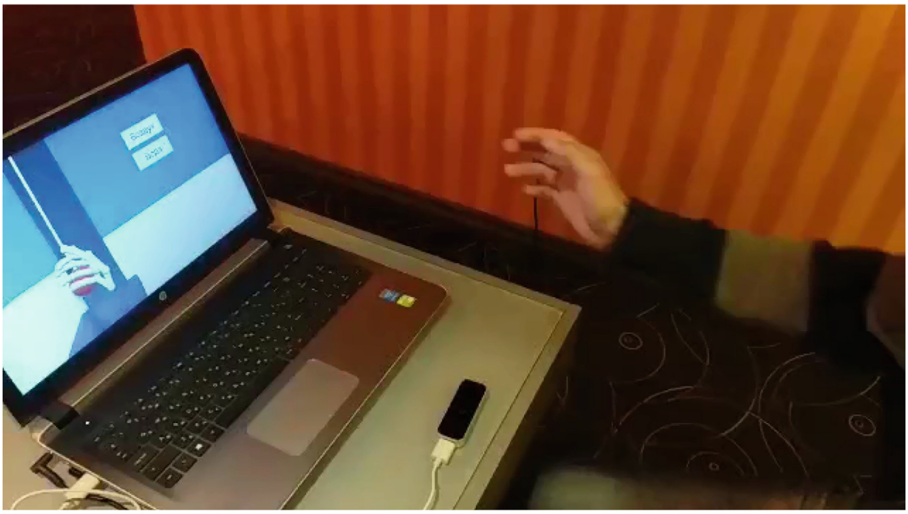


Fig. 1. Main application menu with Leap Motion

Each task contains a condition, an animated task scene and a solution. Let us consider an example of the implementation of the task with a pendulum. The problem task is as follows: will the oscillation period of the mathematical pendulum change if it is placed in water? The pendulum is ideally streamlined, so friction against water can be neglected. A demonstration of the experiment is shown in Fig. 2(a, b).



a)



b)

Fig. 2. The task example with Leap Motion

Interactive control is organized using the Leap Motion controller, keyboard and camera view (mouse control), which also allows you to rotate the 3D scene in different directions. The program also allows increasing the studied objects for a more detailed review. When changing positions and viewpoints, the dialog box is updated. Interactivity in this work is the main advantage, providing visibility and better absorption of knowledge.

In general, the work of the application can be described using the following UML diagrams. The application using Leap Motion consists of the components presented in Fig. 3. It shows the structure of the application. It consists of the Main launch, which opens the application and calls the following two modules: the tasks in the sections “Mechanics”, “Electrostatics”, etc., and the tasks with the Leap Motion controller support. A user can only see the graphical interface, but there are three more components behind them: a shared folder containing models, scripts and other necessary resources, separate folders for a specific task and a folder necessary for Leap Motion to work correctly.

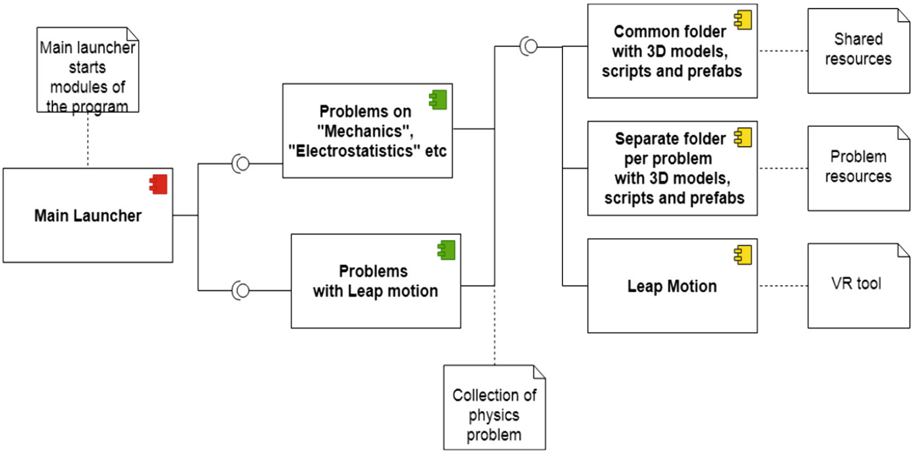


Fig. 3. Component diagram of the application with Leap Motion

The application contains three main classes: MonoBehaviour, MenuControllerScript and LeapManager. Each separate task has its own program code, which is shown as the class ProblemController in the class diagram (see Fig. 4).

User interaction with the application is described in Fig. 5. The possible actions taken by a user are described. For example, at the beginning the user must connect the controller Leap Motion. Only after that all the functionality of the application becomes available to him/her. Then, in the application he/she can select a problem, view the task and the solution, turn on the demonstration, and also change its parameters. All this happens thanks to the Menu Controller as the user interacts with the application with the help of it.

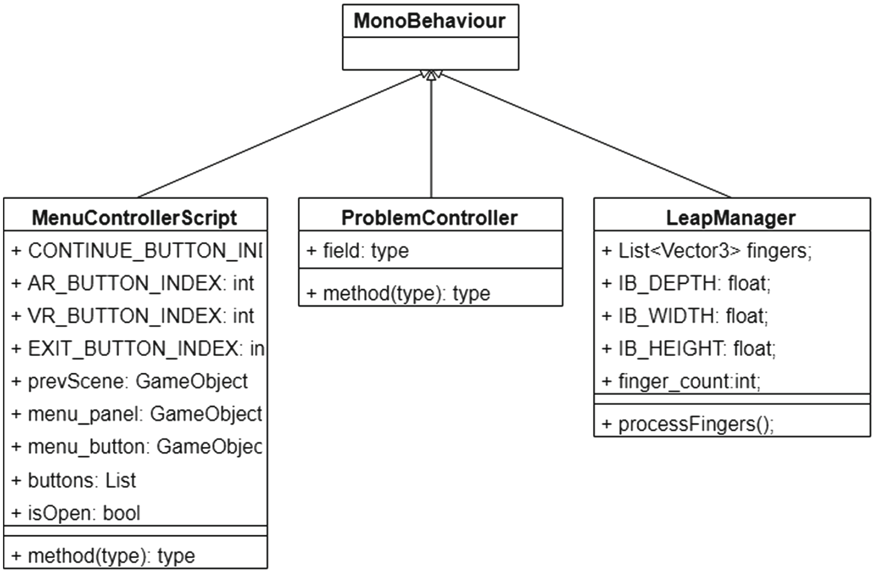


Fig. 4. Class diagram of the application with Leap Motion

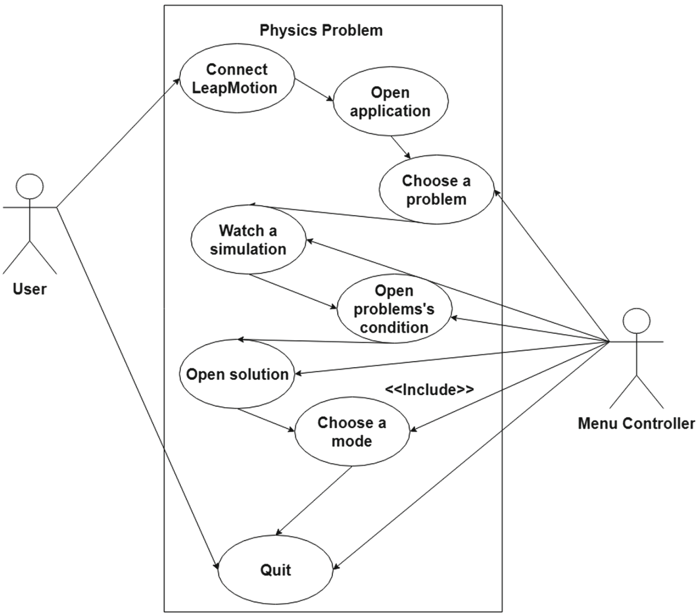


Fig. 5. Use case diagram of the application

5 Conclusion

In order to evaluate the developed virtual laboratory the students of the 9th grade of the Republican Physics and Mathematics School took part in a survey after a month of using the application. The survey consisted of 10 questions about the virtual laboratory, its functionality and the user interface. The results of the survey showed that the students were interested in the virtual laboratory in particular, and in such additional learning tools in general. They expressed their positive impression about the implementation of the application. In the comments they mentioned some points where the laboratory can be improved. And we will take into consideration their suggestions in the next versions of the application.

The teachers totally support the current project and are interested in using the virtual laboratory within classes. Also they expressed a desire to continue the collaboration and to search for new tasks and problems for visualization.

Thus, virtual reality technology opens up new perspectives in education. Along with other courses, physics has a wide potential for the development and implementation of new innovative teaching methods. This article demonstrated a software application to study physics in secondary educational institutions using virtual reality technology. We believe that this application is a good example of modern innovative computer-based learning systems of the new generation. The use of new methods and instruments in education help students to be aware of new trends in information technology field. Currently, the authors are constantly working on the development of new practical tasks as well as virtual physical laboratory works using augmented reality as well. The future work is to expand the functionality of the application by integrating into it new practical tasks from other physics sections, animations that shows the physical processes in detail and virtual physical laboratory works to conduct physical experiments.

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