Virtual and Augmented Reality in Mechanical Engineering Education

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***Abstract* - Nowadays innovative technologies are entering the educational process with the aim of learners easily understanding and learning the material provided. The technologies used and/or based on virtual and augmented reality in the educational process affects today's digital generation and motivation of learners, giving them the opportunity to use their smartphones in the learning process. The aim of the paper is to show the main positive aspects of 3D Virtual Reality environments and 3D Augmented Reality Learning environments in mechanical engineering education. An interactive Mobile Apps for 3D Augmented Reality Learning environment and 3D Virtual Reality Learning environment for setting up and operating a variety of Grinding Devices for Cutting tool sharpening are presented. The Mobile Apps are using Mobile Virtual Glasses suitable for smartphones. The use of 3D Virtual learning and 3D Augmented learning reality in the training of Cutting Tools has been tested with students from the Faculty of Mechanical and Manufacturing Engineering of the University of Ruse. With the Mechanical engineering students, comparative research was conducted to determine the effectiveness of the learning and students' experience level in a 3D Augmented and Virtual Reality Learning environment versus that of a real learning laboratory.**

Keywords – virtual reality, augmented reality, 3D educational process, 3D laboratory, 3D virtual reality, 3D augmented reality

I. INTRODUCTION

Nowadays, technologies and methods of obtaining information that are used require a different level, and new approaches for training in universities to prepare students for the intellectual challenges of the new era. There is a need to develop new educational tools that improve the understanding of the taught material and at the same time speed up the learning process and teach students in engineering specialties with innovative educational technologies. The ideas that are most frequently used to improve the effectiveness of the educational process include replicating the content in an interactive form, if possible, most frequently by making three-dimensional models of the things that are included in the learning material. The popularity of these methods is due to the fact that 80% of learning new material is visual, while only 20% is verbal, i.e. these technologies use the way the human cognitive apparatus is designed for maximum information absorption [1]. Modern educational practices incorporate cutting-edge technologies, such as virtual and augmented reality [2, 3], to make it easier for students to comprehend and absorb contemporary learning content in a fun and engaging way. Today's digital generation students are motivated and more engaged in using technologies based on virtual and augmented reality in the educational process.

One example of a 3D educational program using virtual and augmented reality is AR Liver Viewer, which is utilized in medicine [4]. It displays in real-time accurate anatomical models of the liver. The app was created by a team of anatomy experts, certified medical illustrators, animators, and programmers exclusively for the iPad and New iPad using real CT data and the most precise 3D modeling technologies. The program has two modes of operation. In virtual mode, the user can view the model from all angles, zoom in and out, and focus on a different highlighted area thanks to the 3D display of the model on the application screen. In augmented reality mode, the model is visualized using a marker and the iPad's camera, placing it in actual space in front of the tablet. The ability to rotate the model along all axes, which enables analyzing the appearance and various regions of this organ, expresses the contact with the object.

The usage of markers for viewing three-dimensional objects is noticeable when looking at the current augmented reality solutions applied in the educational process [5]. Due to how easy it is to create applications and show models using this method, marker-based visualization has become the standard method for visualizing 3D models in augmented reality. The fact that some information about the studied objects is visualized in both applications under consideration, whether directly in the program or beforehand in a textbook, leaves an impression. The two augmented reality applications both run on smartphones, but they are designed for different operating systems: one is for iOS and the other is for Android.

InCell VR is an educational game focused on virtual reality technology [6]. The game is of a competitive type and in it the learner is placed in a computer-generated world representing a human cell. The interaction in the game of the learner with the world inside is achieved through the so-called control through gaze (gaze input) and the phone's gyroscope. Initially, the student is provided with an introductory-level option (tutorial). The educational game presents the organelles and other components necessary for human cells in an intriguing way. For instance, proteins have a positive impact on the player's characteristics by giving him more life points and accelerating his movement during the race. In contrast, macromolecules harmful to the cell, in this case viruses, have a negative impact by lowering the player's hit points and slowing down his movement.

For the Cardboard and Daydream platforms, Google built Google Expeditions, which uses augmented and virtual reality for educational purposes. The software offers learners the chance to explore 3D models and 360-degree scenes from various locations around the world. Both iOS and Android devices can use the software. Use the phone's screen or, if one is available, a joystick to select or modify a scene. The user can explore fully produced settings in virtual reality applications, and in the case of Google Expeditions, they are obligated to fully investigate the virtual world. Because both apps are designed for smartphones, it is simple to flip the learner 360 degrees. Since a smartphone is used, these applications are made to work well with them and can be used by many people. Information regarding the objects under consideration is provided by both apps [7].

II. VIRTUAL AND AUGMENTED REALITY FOR MECHANICAL ENGINEERING EDUCATION

A. Comparison of different types of virtual reality helmets

Virtual reality has grown in popularity over the past few years as a result of better picture quality, more user-friendly programs, and more cheap virtual reality helmets. The broad adoption of virtual reality helmets among consumers was also made possible by the hardware advancement of computer components, particularly the video card, a crucial component in virtual reality games and applications.

The helmet, which covers the user's eyes and visually hide the outside environment, is a crucial element when utilizing virtual reality computer programs. In this way, the user is focused on the computer-generated reality, and depending on how realistically the objects are rendered, and how well the helmet and displays are made, the user of the application will have a particular experience. This is called the level of immersion, and in general, in virtual reality, due to the presence of helmets that "hide" the real world from the user, the level of immersion is high.

There are two main types of virtual reality helmets: mobile based virtual reality helmets using mobile phones and computer-based virtual reality helmets, which are more expensive. The technology and software of smartphones have reached a point of development that enables them to run virtual reality apps. The virtual reality helmets used with mobile phones have a distinct structural design from the ones used with desktop or laptop PCs. The helmets, which are used with personal computers, have built-in displays in them. There are two displays total in the "goggles," one for each eye. Without using a common display, each eye receives a separate simulation of the perspective of the created world in this manner.

When smartphone helmets are used, things are different. In most cases, the user sees the smartphone's single display, which is split into two sections for the left and right eyes, respectively. Each eye can focus exactly on the area of the smartphone screen where the image of the computer-generated reality is being displayed thanks to the magnifiers in these "glasses”. Of course, for now, the level of "immersion" in computer-generated reality is far higher with virtual reality "glasses" used with personal computers than it is with smartphones since the resolution of LCD displays and their refresh ability is much higher than that of the smartphone display. However, the refresh rate of modern smartphone screens, which is more than 60Hz, is sufficient for them to work effectively with computer-generated content, and the resolution increases with each new generation of these devices. Table 1 presents a comparison between different VR helmets.

TABLE I. A COMPARISON BETWEEN VR HELMETS – TYPE 1

Name	View angle, °	Resolution, pixel	Refresh rate, Hz
Oculus rift	110	2160 x 1200 (1080 x 1200 per each eye)	90
HTC Vive	110	2160 x 1200 (1080 x 1200 per each eye)	90
Daydream	100	Depending on the smartphone	Depending on the smartphone
Gear VR	96	2560 x 1440	60
Zeiss VR ONE	100	Depending on the smartphone	Depending on the smartphone
FreeflyVR Beyond	120	Depending on the smartphone	Depending on the smartphone

As can be seen from the table, the refresh rate of smartphones is lower than that of displays in helmets that connect to a computer, but not by much - on the order of 30Hz.

In order to use virtual reality helmets with a personal computer, it is required to use USB and HDMI cables between the glasses and the computer. As a result, the user's ability to move and rotate 360 degrees in the virtual environment is limited by the presence of cables that, when rotated, have a certain length, and have the potential to twist. This poses a risk of damage to the glasses and/or the PC as well as the user's safety while wearing the glasses.

Since cellphones are used with virtual reality headsets, this issue is avoided because there is no need for wires because the device is housed inside the "glasses." This permits 360-degree panning and rotation, allowing for the viewing and exploration of every point in the computer-generated world.

The following Table 2 compares several virtual reality helmets based on the device type — wired or wireless — and other factors that are taken into consideration while picking eyewear.

The table shows that smartphone-based helmets allow the operator more mobility because they don't require a cable connection.

The sensors required to function in the virtual world, such as a gyroscope, etc., are another component of the table that need our attention. Such sensors are not included in smartphone helmets because they are part of the phone itself. Therefore, the same sensors can also be utilized in mobile device virtual reality applications.

TABLE II. A COMPARISON BETWEEN VR HELMETS - TYPE 2

Name	Type	Brand	Price less than, €	Software bundle	Sensors
Oculus rift	Cable	Oculus (Facebook)	700	Oculus SDK, SteamVR SDK	Accelerometer, gyroscope, magnetometer
HTC Vive	Cable	HTC	730	SteamVR SDK	Accelerometer, gyroscope
Daydream	Wireless	Google	120	Daydream/ Cardboard SDK	From the smartphone
Gear VR	Wireless	Samsung, Oculus	110	Oculus SDK	From the smartphone
Zeiss VR ONE	Wireless	ZEISS	150	Daydream/ Cardboard SDK	From the smartphone
FreeflyVR Beyond	Wireless	FreeFlyVR	65	Daydream/ Cardboard SDK	From the smartphone

Different virtual reality helmet manufacturers offer different software packages for application creation, with smartphones primarily adopting the Daydream/Cardboard technologies' Daydream software package.

The price of the smartphone is not considered as can be seen from the table and the price difference between the two types of helmets because these devices are typically used for various purposes and their price value is also influenced by other factors and usage scenarios. Because of this, computer helmets do not factor in the cost of personal computers. It is important to note that PCs and smartphones with varying price ranges will perform differently in virtual reality programs, accordingly.

B. Design Process of Virtual and Augmented Reality Applications for Mechanical Engineering Education

The main purpose of the paper is to present 3D virtual reality and 3D augmented reality apps for educational purposes and more specific for mechanical engineering education. Both applications were created at the University of Ruse and are used to educate students in the course of Cutting Tools. Students learn about various cutting tools with extremely complex shape and cutting geometry [8], their parameters and characteristics, how they work [9], as well as how to repair them if they become worn out.

The Cutting Tools textbook's figures are recognized as markers by the augmented reality software, which then launches corresponding 3D files of the studied machine tools, orienting devices, or cutting tools. In this way, students can visually get to know the studied objects in much bigger details. The second application is for a virtual reality. The students even in pandemic situation can enter a virtual laboratory room, where the sharpening processes of various cutting tools, the cutting tools themselves and the orienting devices can be examined in details. For both applications students can simply use their smartphones.

There are many software solutions for building three-dimensional models, which at the same time offer the possibility of optimizing the models. The same programs also offer the option of texturing the objects, but there are also specially created applications for this purpose. Regarding augmented reality technology – there is also a choice of technological solutions serving to implement this possibility in mobile applications. With smartphone virtual reality, we have a narrower choice of technologies provided to implement such applications.

Programs for creating 3D models can be divided into two groups - those that create accurate technical models (CAD systems), but at the same time do not create visually attractive models. The second type of programs are those used in making games, movies, advertisements, etc. These programs create the so-called CGI (Computer-generated Imagery) and they aim for a better visual representation of the object, as the technical parameters remain in the background. However, the programs through which CGI is created also allow an accurate description of the dimensions of the modeled object, which, together with the greater possibility of visual modeling and presentation of the objects, is the preferred choice for creators working in the field of augmented reality and not only.

Regarding the creation of augmented and virtual reality applications, the Unity 3D computer game creation software is mainly used. To implement the two applications, implementing the two different technologies, a solution should be chosen from the available software packages, which will best support and facilitate the development of the two applications and the possibilities it offers to enable the realization of the set goals.

For the needs of augmented and virtual reality applications, models of machines used in practical training in the discipline "Cutting Tools" were selected. Some of the models that are related to the figures in the textbook were selected specifically in the context of the teaching material of the printed textbook. Machine models are created in a CAD modeling computer program. The peculiarity here is that with these programs accurate engineering models are created, in the context of three-dimensional CAD programs. These programs are used by engineers to create accurate models that are then, most often, created in the real world. The models are mathematically accurate and consider all the characteristics of the object - size, the material used to manufacture it, distances between parts, etc.

Because of this detail required in engineering designs, the skeleton of 3D CAD models consists of multiple faces to make the model as detailed as possible. For this reason, when visualizing such models in a professional setting, computers with powerful and expensive CPUs and video chips are used, which allow the three-dimensional models to be visualized and interacted with visually, such as being viewed from different sides, in a fast and smooth way.

Visualizing such models using commercially available PCs and smartphones is a labor-intensive task due to CPUs with lower frequency and cores and GPUs with significantly fewer cores, clock speeds, and memory. In this case, the smartphone will be used to work with the applications - a device whose hardware capabilities are even lower than those of personal computers. Therefore, these models need to be optimized in order to run the applications correctly.

The main method that was used is called retopology. This is a method in which the skeleton of the three-dimensional model (mesh) is recreated in an optimal way without losing visual information. Mainly, retopology consists of reducing the number of faces and converting them from triangles and polygons to squares or rectangles. The optimized model, whose surface now consists of fewer quadrilateral faces, is easier to work with in texturing programs and requires less device hardware resources to render.

Machine tools 3D models were optimized following the following steps:

- Removing duplicate vertices from the model skeleton. Three or more of these vertices form the face of the model skeleton. When you delete one of these vertices, the face collapses and is removed from the model. This is the first method that is used;
- The next step is to convert some of the triangular faces from the skeleton into quadrilaterals by merging the adjacent triangles into a quadrilateral. This again reduces the number of faces, and already quadrilateral faces, as mentioned earlier, are more convenient for texturing and visualization;
- This is followed by removal of geometry that is not needed for the presentation of the model, but remained after the work on it. Such geometry is, for example, angles without length, quadrilaterals with zero area value, etc. Although this geometry does not exist visually, it is respected by the program and added to the model, therefore it is taken into account when rendering it by the application and occupies graphics memory;
- The number of vertices and faces is reduced by a method called "decimate". Through various parameters, such as face-vertices ratio, groups of vertices per area, etc. the number of faces in the model is reduced;
- Finally, a method is resorted to, by which persons are united to the so-called boundary angles, i.e. angles separating different planar regions of the model geometry. Thus, in different areas of the model, faces are minimized, generally reducing the number of faces in the model geometry without leaving gaps in the model skeleton.

Following these steps visually optimizes model geometry and reduces the number of faces, ensuring proper texture placement and rendering with fewer hardware resources in augmented and virtual reality applications. The optimization was performed using the Blender programming environment. The ultimate goal is for models to have a geometry face count of up to 30,000. This number takes into account the hardware capabilities of modern and older devices so that models are rendered smoothly and interact smoothly without traffic interruption.

C. Design of Virtual Reality Application for Mechanical Engineering Education

The virtual environment for the virtual reality application is a laboratory room with a table in front of the user's "eyes" on which the models will be visualized. The lab was created entirely in Blender 3D modeling software. The final appearance of the virtual room is presented on Figure 1.

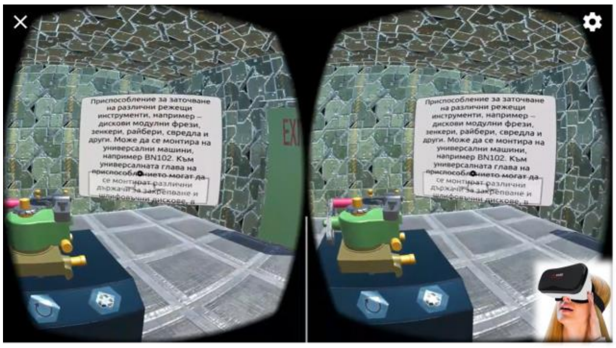

Figure 1. Virtual Reality Laboratory room

Model of an orienting device for sharpening a disc modular cutter

The model is an orienting fixture device holding firmly various cutting tools still during sharpening or resharpening the cutting edges, for example – disc modular cutters, countersinks, reamers, drills, etc. The orienting device can be mounted on universal sharpening machines, for example BN102. Various clamping holders and grinding discs can be used / shown, depending on the tool to be sharpened. The sharpening machine also allows making various settings, such as limiting the longitudinal movement of the table. The model was initially built from 45,941 faces with varying numbers of face angles. Although the number of faces is acceptable, optimization is needed to avoid problems in creating the texture of the model. After optimization, most of the faces of the model are in the form of quadrilaterals, and the number of faces is reduced to 17,062. Thus, after optimization, the geometry of the model is significantly cleaner, i.e. the shape and area of the polygons is optimized, which is a prerequisite for smooth texturing of the model, and the smaller number of faces means relatively less hardware load on the learner's device. The model before and after transformation is presented on Figure 2.

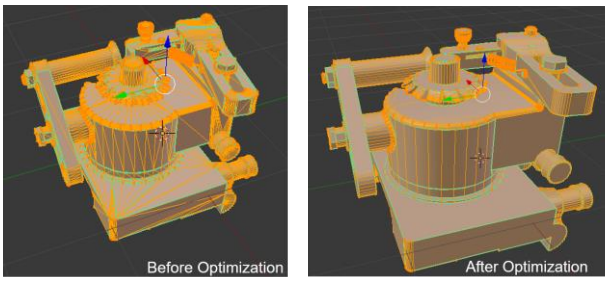

Figure 2. 3D model of orienting device for sharpening a disc modular cutter before and after optimization

Model of an orienting device for sharpening a worm modular cutter (hub)

Initially, the geometry of the sharpening machine model consisted of 83,386 faces. The model consists of multiple polygons with more than 4 corners, which when texturing would create a problem in the texturer. The number of faces of the model before optimization would also create a problem when rendering the model and applying transformations, related to more work on the CPU and graphics chip and the resulting heat dissipation and battery drain. After applying the optimization steps explained above, the model retained its appearance without loss of visual information. Now most of the polygons are quadrilaterals and the faces of the model geometry are now 22,359. So the model will be easier to texture and the smartphone hardware will be significantly less loaded when rendering and transforming the model.

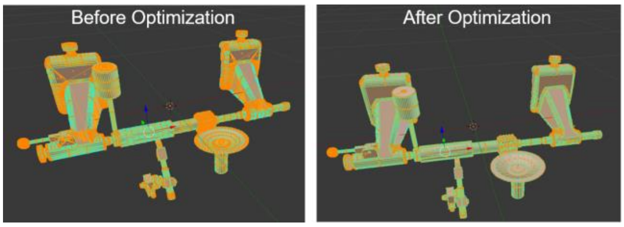

Figure 3. 3D model of the orienting device for sharpening a worm modular cutter (hub) before and after optimization

Unity Game Engine along with Google Cardboard SDK is used to create the virtual reality application. The application works with a single scene, which is essentially the virtual environment. The app also has built-in text visualization objects so that the information needed for each model can be visualized in the virtual lab (Figure 4).

Figure 4. Text visualization functionality

Worm modular cutter (hub)

The hub cutter model consists of 20,712 faces. This number of faces fits within the initially established upper limit, but we have polygons from the model skeleton with a large number of corners and this would cause difficulties when applying the texture.

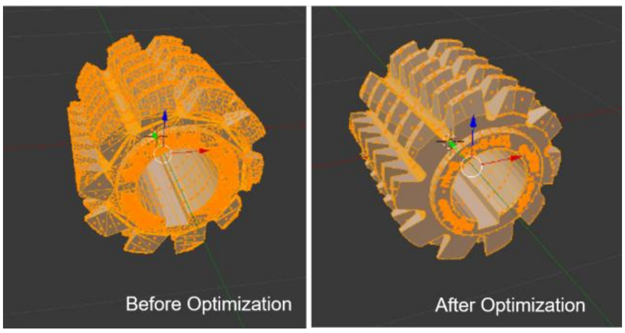

Figure 5. 3D model of the hub cutter before and after optimization

After optimization, most of the faces of the geometry were converted to quadrilaterals and the number of faces was reduced to 3,314, without loss of visual information. The model before and after optimization is presented on Figure 5.

Additional challenge which we faced with was the way users work in the Virtual reality environment. The presented Virtual reality application is providing "Rotation" functionality around two of the axes which are horizontally positioned. Using Rotation around only two of the coordinate axes gives simplicity in the way the users operate and work with the Virtual models, the functionality is shown on Figure 6.

Figure 6. Two axis rotation of the hub cutter 3D model

D. Design of Augmented Reality Application for Mechanical Engineering Education

Since the augmented reality application is marker-based, markers need to be identified and embedded to be scanned by the application and the three-dimensional model to be visualized accordingly. Due to the fact that this application will be based on an already existing textbook that is used in face to face education, it was decided that the markers will actually be figures from the textbook, Figure 7. This way, there is no need to create an entirely new marker system to embed in the textbook and reprint it in large quantities. Using ready-made figures from the textbook to create the markers saves a huge amount of financial and time resources that would otherwise have to be booked to creating a textbook to work with the application.

Figure 7. Augmented Reality App visualize 3D model on textbook

The following steps were used to create the tags for augmented reality application:

- First, the textbook figures for the required models were photographed using a camera. The photographs were then copied to a personal computer;
- Second, by using Vuforia's built-in tagging system, the photos were uploaded to the web

application Vuforia Developer Portal, where their system converted them into augmented reality tags;

- Finally, after all the shapes have been converted to markers, the package created by the Vuforia system is downloaded, ready to be embedded in Unity.

Following the completion of all these stages, the resulting tags are embedded into the development environment using the unity package that was obtained from the Vuforia system, allowing the user to decide which model is visualized by each tag (shape/marker).

The augmented reality application is implemented in the Unity Game Engine using the Vuforia SDK. The app works with one scene where all the models and targets are embedded.

E. Students Feedback and Survey Results

It is crucial for the apps' design process to receive feedback from students. The apps were iteratively tested with students in University of Ruse. The tests showed that the applications work according to the intended logic and some recommendations were made to improve better performance. The "Reset" button was added to the augmented reality app, and the font and size of the content in the same app were altered based on user feedback. The format of the visualized information was altered in the virtual reality application, specifically by reducing the area where the text is displayed and by including additional buttons for a kind of information scrolling. The details for each model include test questions and answers.

An online survey was made with students to assess the level of student satisfaction using the applications for augmented and virtual reality. Students must respond to multiple questions regarding various aspects of apps functionality. Survey results shows that 91 % of students think that the interaction with the 3D models in the augmented reality application and the virtual environment in the virtual reality application is intuitive and easy to learn and use. 86 % answers that interaction with the apps are fun and more engaged. 89 % of the survey attendants who used the apps agreed that the apps would be important asset of the Mechanical engineering education and prefer to use them in their studies.

III. CONCLUSION

To meet the current state of technical growth and the intellectual capacity of modern learners, education, like nearly all aspects of social life, is susceptible to modernization. The introduction of new technologies such as virtual and augmented reality helps to show the items in the studied disciplines in a unique, understandable, and fascinating way, changing the mechanical engineering educational content and the ways of its assimilation.

The 3D visualization of models of the cutting tools and orienting devices used in training of students through augmented and virtual reality technologies is an innovative and interesting approach that supports the effectiveness of learning by providing the opportunity for learners to enter to the virtual learning laboratory or simply 3D visualize a given machine tools or cutting tools from the standard textbook.

As a conclusion some features, positive and negative sides of virtual and augmented reality educational tools can be summarized:

• The use of marker-based visualization of models is a preferred approach when the dimensions of real objects represented by 3D models are relatively small;

• The use of smartphones in the classroom demonstrates a new paradigm for students where these portable devices can be used as effective learning tools.

• The usage of smartphones or other cordless portable devices, like a tablet, allows greater flexibility in the use of the applications because the augmented reality application doesn't need any extra hardware. The required equipment is also simple for the virtual reality application- just a helmet for smartphones which is not expensive;

• As portable devices offer greater freedom of use of the learning tool it is crucial to choose a method of developing the application that can be easily implemented in the two most popular mobile operating systems, Android and iOS;

• In the application implementing virtual reality technology, it is important to create a complete virtual environment that can be viewed by rotating 360 degrees.

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