

Data Analysis using Augmented Reality Visualization

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Abstract

In this paper, the authors describe the history of augmented reality and its applicability in scientific visualization and visual analytics. The study explores the benefits of using this technology for analysts studying spatial scenes and presents an advanced online platform for creating augmented reality projects used for educational purposes.

Keywords: Augmented reality, scientific visualization, visual analytics.

1. Introduction. Review of Augmented Reality Research.

In today's world, people interact with vast amounts of data, which is why most technologies are aimed at simplifying the acquisition and perception of information. One such technology is "augmented reality," which has been the subject of extensive research since 1967. The term "Augmented Reality" was first introduced in 1990 by T. Caudell, a researcher at Boeing, who defined it as follows: "Augmented reality is a technology that allows graphical information to be displayed directly onto the human retina using various technical devices."

The authors of this article consider augmented reality systems (ARS) as a specific case of spatial modeling and visualization systems. Spatial modeling is used in the creation and editing of spatial scenes, while visualization is used for their visual representation. It should be noted that the specificity of ARS lies in the extensive use of various complex imaginary material and abstract objects of spatial scenes, as well as the wide range of visualization attributes for such scenes.

Figure 1 illustrates an example of ARS. It shows a tablet running a special mobile application that uses image recognition technology to track a drawing on the table and overlay a virtual spatial scene with objects onto the scene, represented as a 3D model of the surroundings of the Eiffel Tower, which was created in a special program (see Fig. 1).



Fig. 1 - Spatial modeling and visualization system of a spatial scene consisting of a three-dimensional model of an abstract object, in the form of the surroundings of the Eiffel Tower, displayed using ARS.

On Figure 2, an illustration of another example of ARS is shown. It can be seen that a tablet running a special mobile application uses object recognition technology to track a mechanical installation and then overlays a spatial scene on it. The virtual objects in the scene include a virtual layer that shows the boundaries of the installation, as well as virtual objects in the form of pointers and labels for the 6 stators (see Fig. 2).



Fig. 2 - Spatial modeling and visualization system of a spatial scene consisting of a three-dimensional model of an abstract object, in the form of an installation shell, as well as additional objects in the form of pointers and labels on its 6 stators, displayed using ARS.

When it comes to the history of Augmented Reality (AR) technology [9], the idea of overlaying data onto real-life through technological devices was first described in the novel "The Master Key" in 1901 by L. Frank Baum. In the novel, electronic glasses were used as the device. In 1962, Morton Heilig invented the Sensorama, a simulator that provided sound, visual effects, and even vibrations. However, the birth of augmented reality is considered to be in 1968 when Ivan Sutherland invented the "Sword of Damocles" head-mounted display, which was positioned as a window into the virtual world. In 1974, Myron Krueger opened the "Videoplace" laboratory in Connecticut, dedicated to artificial reality. In 1980, Steve Mann created the EyeTap, a head-mounted display that showed virtual information in front of the user's eyes. This device is considered the first functional model of an augmented reality headset. In 1993, the first experimental implementations of AR in real cars and pilot simulators by Loral WDL took place. In 1998, the first implementations on television occurred when Sportvision displayed the yellow line during an NFL game. In 2000, Hirokazu Kato created the ARToolKit [20], a software library that is still used today and has open-source code. In the same year, the first AR game called AR Quake was developed. The first uses in print media occurred in 2009 when Esquire magazine used AR to bring their cover to life by adding a computer layer with video. Also in 2009, ARToolKit [20] was ported to Adobe Flash (FLARTToolKit [21]), allowing Saqoosha to bring AR to web browsers. In 2012, the UK-based company Blippar created the first cloud-based AR application. Volkswagen also made a significant contribution to the development and application of augmented reality by creating the Marta application in 2013. It provided repair instructions for specialists and was innovative. Later, it found applications in various industries. The well-known Google Glass eyewear was developed in 2014, and in the same year, Blippar [22] created the first game for them. Following Google, Microsoft didn't keep us waiting and introduced HoloLens in 2015, a mixed reality headset that surpassed Google Glass. In the same year, the Association of Augmented and Virtual Reality was established in Russia. The most famous augmented reality game in the world was "Pokemon GO [17]," created in 2016, which significantly changed consumers' skeptical attitude towards innovative technologies. In 2017, Apple

announced one of the most popular tools to date - ARKit [16], which is used to create mobile applications with augmented reality. In the same year, the number of AR users in the United States reached 37 million people, and some attribute this to IKEA releasing the IKEA PLACE app, which transformed the retail industry.

ARCore [18] – the most popular tool for Android device developers – was announced by Google in 2019, following Apple's ARKit [16]. Most augmented reality applications are created using ARKit [16] and ARCore [18], and this trend continues to the present day.

It is important to classify Augmented Reality (AR), as described in the research paper "Classification of Augmented Reality Applications" by Makolkina M.A. [1], written in 2020. Augmented reality systems are classified based on:

1) Type of information representation:

- Visual: Information is presented to the user through images.
- Audio: Information is presented in the form of sound.
- Audiovisual: Combination of visual and audio information.
- Text and graphic systems: Information is presented as text.
- Sensor-based: Information is provided through vibrations.
- Holographic: Information is presented using holographic images.

2) Degree of mobility:

- Stationary: These systems cannot be moved without causing malfunctions.
- Mobile: These systems can be moved without any disruptions.

3) Degree of user interaction:

- Autonomous: The system's task is to provide the user with the necessary information.
- Interactive: The system actively interacts with the user, providing responses based on user actions.

4) Method of trigger recognition (the object or situation that triggers the appearance of augmented reality):

- Markerless Augmented Reality: No markers or triggers are required.
- Marker-based Augmented Reality: Requires a marker as a trigger.
- Geopositional: Requires GPS and accelerometer signals to determine the angle of rotation relative to vertical and azimuth.
- Image recognition: Requires an object trigger (face, image, hands, or any other objects).

When it comes to the application areas of augmented reality (AR), they are very extensive. For example, Pantano [6] (2014) emphasizes the potential of augmented reality in terms of "capturing consumers' attention and influencing their purchase decisions." With the recent emergence of augmented reality and its increasing accessibility, retailers have started relying on this interactive technology to enhance the shopping experience and influence the decision-making process of potential buyers. On one hand, interactive technologies in shopping centers use specialized devices and software to explain, demonstrate, and recommend products. On the other hand, mobile applications with augmented reality features can be downloaded and installed on users' personal portable devices, making them available anytime and anywhere, and therefore more frequently used and helpful for users. In addition to adding informativeness, the wow-factor that this technology brings cannot be denied. Due to its novelty, users are more willing to use it more often compared to familiar technologies. Nowadays, augmented reality is applied in various areas of our lives, including education, marketing and advertising campaigns, proprietary augmented reality products in the banking sector, and more.

According to many scientific articles [1], optimal applications of augmented reality are in retail and the commercial sector as a whole. Augmented reality is widely used for virtual fitting of clothing and trying out technology and furniture in one's own interior space. However, the applications of augmented reality technology are not limited to these areas. In our view, one interesting and rational application of this technology could be its integration into the data analysis process in visual analytics. Currently, there is relatively little research in

this area, but such an application could be highly effective and will be described in detail in the next chapter.

2. What is visual analytics, its achievements and challenges? The role of augmented reality.

James Thomas, an American scientist, formulated a set of ideas and concepts in the paradigm of visual analytics for solving data analysis tasks using a supporting visual interactive interface. One of the most widely practiced examples of visual analytics may be the solution in terms of data analysis through visualization methods. The main essence of this method is as follows: a static or dynamic graphical image is associated with the object of consideration, which is visually analyzed. The results of data analysis are interpreted graphically in relation to the original data and the object of consideration (see Fig. 3).

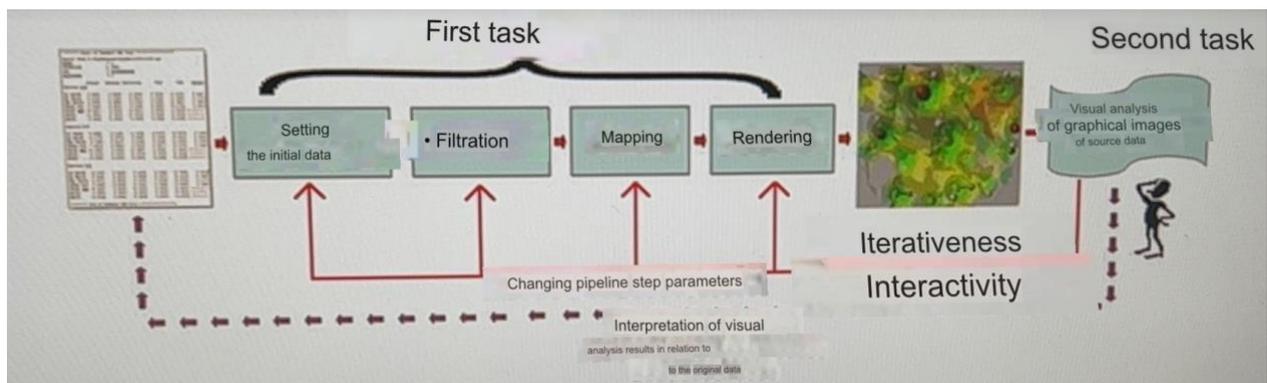


Fig. 3 Data analysis through visualization methods

What is visual analysis of graphical data? It is important to note that visual analysis follows spatial modeling of the original data. This means that the obtained graphical images are intended to serve as a convenient and natural means of spatial interpretation of the original data for analysts. The interpretation of the spatial scene involves a series of spatial objects (either one or multiple) that are mapped to the analyzed data during the so-called mapping stage. The spatial scene is visually analyzed. Subsequently, the results are interpreted in relation to the original data. Visualization method, as a data analysis technique, is one of the methods used in spatial data modeling. This allows for leveraging the vast capabilities of spatial thinking by analysts during the analysis process. Ultimately, analysts make judgments about the analyzed scene. As mentioned above, these judgments are interpreted by the analyst in relation to the original data, forming a judgment model about the object of consideration. In general, data analysis using visualization methods can be interactive, iterative, and complex.

It is important to note that visualization methods can be used to analyze data of various types, such as different experimental and theoretical scientific data, which constitute the essence of scientific visualization. Consequently, in data analysis using visualization methods, the central focus is on the spatial scene, which is mapped by the analyst to the analyzed original data and visually analyzed. During the analysis, visual analysts perform several basic operations on the spatial scene, including analyzing the spatial arrangement of data components, analyzing the shape of spatial scene components, and analyzing their color representation.

These operations have a qualitative nature, and it is expedient to introduce additional spatial objects into the spatial scene that are not directly related to the original data but allow for an increased resolution in analyzing the original data. These additional spatial objects, like the spatial scene itself, can be either static or represent spatial processes. In modern computer science, the result of introducing the spatial scene and similar auxiliary spatial objects into the visual field, through technological devices such as smartphones, tablets, and

computers, for the purpose of analyzing the spatial scene, augmenting information about the environment, and altering the perception of the surrounding environment, as described in the previous chapter, is referred to as augmented reality. It is important to note that as a result of such introduction, not only do new additional objects appear, such as elements of the spatial scene display interface, but the appearance of the spatial scene itself is also altered.

With augmented reality technology, analysts have the ability to analyze the spatial scene on smartphones and tablets. This makes spatial scene analysis more accessible to a larger number of analysts. This type of spatial scene display always occurs against the backdrop of the working camera of one of the aforementioned technological devices, through the operation of a specialized mobile application or in a browser. It is precisely the accessibility of using this type of display for subsequent analysis, as well as the presence of additional objects within the spatial scene, that allows for informed recommendations on the rational use of augmented reality in visual analytics. It is important to understand at this stage whether augmented reality is already being used in the areas related to scientific visualization and visual analytics or not.

In the work of Mrudang Mathur and others (2022), models of augmented reality applicable to scientific visualization are described. It is reported that this technology is rarely used in scientific visualization due to the difficulty of creating it. It is also emphasized that previously there were no accessible means for creating augmented reality. The next chapter of this article will describe one of the available online platforms for augmented reality projects, which makes it easy to create such projects.

In the work of Namiot and Romanov (2018) titled "3D Visualization of Architecture and Software Metrics," they demonstrate how a pre-created 3D model of a "software city" is embedded into a real scene using augmented reality technology. This shows an example of how spatial scene analysis can be simplified for analysts using this technology.

In the work of Vakhrushev (2020), models of applying augmented reality for visualizing scientific knowledge in an open library archive are described. Augmented reality enhances the informativeness of the spatial scene in this context.

3. Participation in the work on the use of AR in visual analytics at NRNU MEPhI LLC "AR Studio"

In the Russian market of augmented reality, there is a monopolistic company among online platforms for creating augmented reality projects - the Web-AR.Studio platform [11]. It functions as an online constructor, where even a person without programming experience or knowledge of 3D graphics can create their own augmented reality project in a matter of minutes. Moreover, projects can be of any complexity and can work both through a mobile application and through a browser, eliminating the need for mobile apps. This online platform was created by two students of NRNU MEPhI, and as a result, it was made available for use by master's and doctoral students of NRNU MEPhI in disciplines such as "Scientific Visualization" and "Visual Analytics".

During the planned sessions, doctoral and master's students will create three-dimensional models based on scientific data using the "3Ds MAX [13]" program. Subsequently, these data models will be integrated into augmented reality projects using the Web-AR.Studio platform [11]. This allows analysts to analyze them from any device, such as a smartphone, tablet, or laptop. Additionally, by adding additional interface icons on the online platform, the informativeness of the spatial scene for analysts can be increased, as shown in Figure 2. The relevant work of doctoral and master's students can be used in the Department of General Physics for teaching students in introductory courses. The integration of such augmented reality projects in physics labs enhances student engagement, resulting in improved preparedness and faster comprehension of information. The engagement of an augmented reality project is achieved through the interactivity of this technology. The speed

of information comprehension is achieved through the additional interface and three-dimensional visualization, which is easier to perceive than two-dimensional information. As humans perceive the world in three dimensions, three-dimensional objects in augmented reality are also quickly and easily understood compared to two-dimensional ones.

There is also an ongoing scientific seminar on the topic of "Visual Analytics and the Use of Augmented Reality Technology to Solve its Tasks." During this seminar, participants can learn how to effectively utilize this technology to solve "visual analytics" tasks.

Regarding the general characteristics of the work on using augmented reality in visual analytics tasks at NRNU MEPhI, using the online platform of AR Studio LLC, a range of tasks related to the visualization of physical processes from student laboratory work can be highlighted, as well as their work with physical installations located in the general physics laboratories. NRNU MEPhI master's and doctoral students will be able to recreate processes from methodological printed documents for student laboratory work using augmented reality technology. This will allow for faster perception and, as a result, better assimilation of new information for NRNU MEPhI students. Currently, everything is presented in a 2D format, in the form of printed documentation with images, but it will be presented in a 3D format through AR technology created on the online platform.

Regarding the description of the online constructor itself, on the Web-AR.Studio platform [11], you can create an augmented reality project in three different deployment variations (see Figure 4): browser-based applications, mobile applications, and instant launch applications. Browser-based applications work without the need to download a mobile application, so the user does not need to spend personal time and storage space on their device, such as a smartphone. However, the downside is that the recognition algorithm in browser-based applications is considered less stable and slower compared to the mobile application. On the other hand, the advantage of the mobile application is its fast recognition algorithm, but the downside is the need to download the application. As for the instant launch application, it combines the advantages of the first two options, meaning it does not require downloading and has a very fast recognition algorithm. It is important to note that different types of publications have different maximum numbers of simultaneously recognizable triggers. For example, a browser-based project can have up to 9 simultaneously recognizable images and up to 1000 simultaneously recognizable QR codes, while a project in a mobile application can have up to 100 simultaneously recognizable images. Additionally, you can choose one of the recognition types, which can be QR code recognition, image recognition, or markerless technology, as shown in the example with solenoid magnetic fields (see Fig. 9).

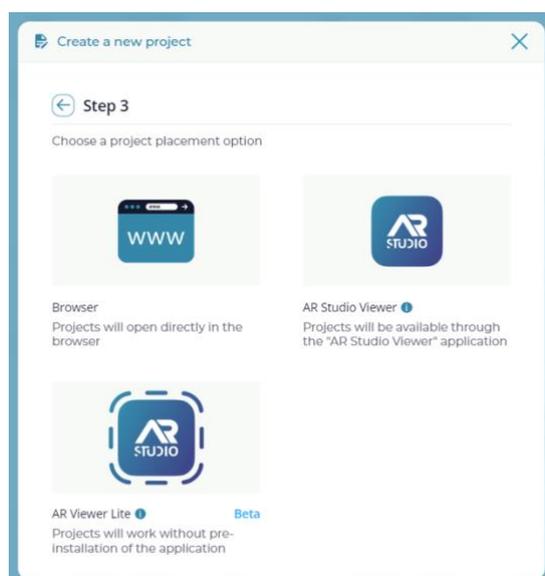


Fig. 4 - Three deployment options for projects on the Web-AR.Studio platform [11]

If you have any questions about creating a project, you can ask the technical support team by clicking on the "Help" button or refer to the platform's documentation by clicking on the "Training" button.

Opening an augmented reality project is done through a QR code generated based on the project's URL. On the platform, in the top left corner of the project's main page, you can download it in various formats such as JPG, SVG, PNG, or PDF. If marker-based augmented reality technology is used, you can download the combined QR code and project trigger. A trigger is an object that triggers the appearance of augmented reality. For example, if image recognition is used, the video stream obtained from the device's camera will be divided into frames, each frame will be processed and compared with the uploaded image on the platform. If a match is found, virtual augmented reality objects created by the user on the online constructor will appear at the location of the recognized image.

When using the "Web-AR.Studio [11]" constructor, there are also several auxiliary functions to enhance the user's interaction with the project. These include:

- 1) Project personalization, which allows you to choose the project's language, domain name, loading screen, and logo.
- 2) Custom analytics system, which collects data on user interaction and experience.
- 3) The ability to disable the project trigger through the default scene fixation button, to switch the project type to markerless. This button is shown in the top part of Fig. 7. Additionally, you can integrate well-known analytics systems such as "Yandex.Metrica [15]" and "Google Analytics [16]".

In the editor itself, you can choose from pre-designed project templates and modify the data to fit your needs, or create your own project from scratch. There are two types of editors available: a 2D editor for beginners and a 3D editor for advanced users (see Fig. 5).



Fig. 5 - 3D editor of the Web-AR.Studio platform [11]

In the editor itself, when creating a project, you can upload the project trigger in the top right corner or, if there are multiple triggers, apply batch uploading, which allows you to apply up to 100 images as triggers at once.

Through the toolbar located in the top left corner, you can upload various types of augmented reality objects, including audio, text, images, videos, videos with alpha channel, static 3D models, animated 3D models, and built-in geometric objects.

For example, in the work "Cyber-Physical Museum Exhibits Based on Additive Technologies, Tangible Interfaces and Scientific Visualization" (2019) by K. V. Ryabinina [24] and others, a 3D model of a "Bonobo" skull is described and visualized, created by scanning a

real skull with a 3D scanner. It can be integrated into this platform as a 3D model for subsequent viewing in augmented reality.

Each augmented reality object can have its own functions that will be triggered when the element is clicked. Additionally, objects can have animations. In this platform, you can modify the design of objects, their position in space, transparency, color, layer position, and in the 3D editor, you can modify the texture and relief of the 3D model.

Furthermore, you can even set up lighting within the project, similar to how it is done in 3D modeling programs like Blender [12] and "3Ds Max [13]". You can choose from different types of lighting, such as spherical, directional, point, spotlight, and ambient lighting (see Fig. 6).

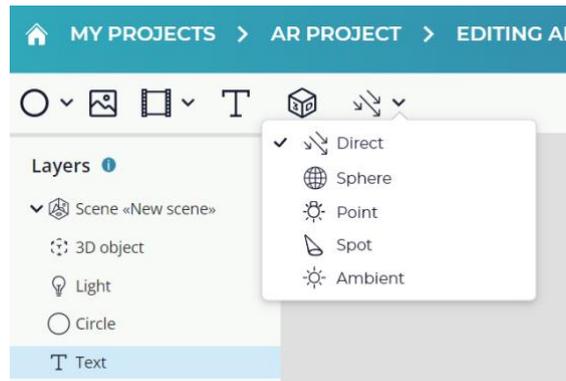


Fig. 6 - Toolbar on the Web-AR.Studio platform [11] with the option to select the type of lighting.

As seen in Figure 6, each scene is divided into layers consisting of augmented reality objects. There can be multiple scenes, and depending on whether the same triggers have different scenes or not, projects can be created for different purposes. If a project contains a large number of triggers, and each trigger has its own virtual scene, it is called a multi-trigger project. For example, a brochure, album, or book with augmented reality, where each page is recognized individually and triggers the appearance of different augmented reality objects on the device.

When a user finishes creating an augmented reality project and wants to preview the result, they need to click on the "Preview" button located in the top right corner. This will bring up a preview window with a QR code and trigger (see Fig. 7).

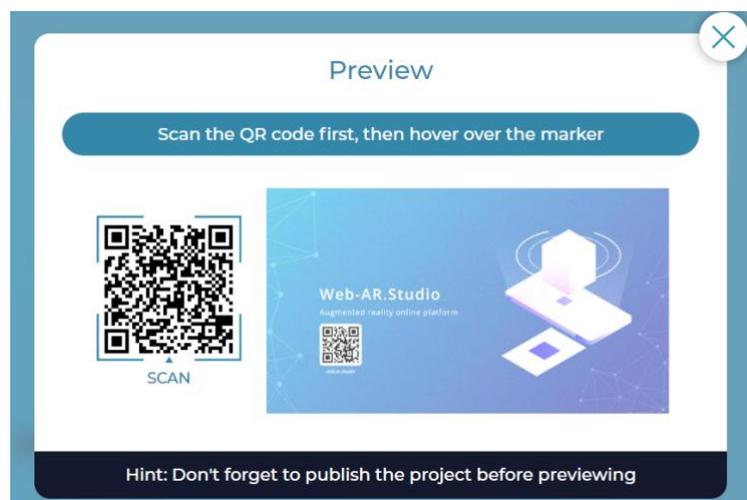


Fig. 7 - Preview on the Web-AR.Studio platform [11]

This constructor allows you to create augmented reality projects where you can use your own pre-made 3D models and add additional objects to create a spatial scene that provides

additional information. For example, in Figure 8, an animated 3D model of a heart is shown, with the ability to click on the screen on one of the virtual objects located next to different parts of the heart and read about the functions of that specific part.

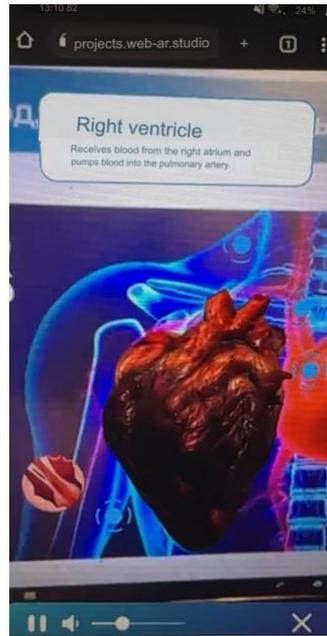


Fig. 8 - Augmented reality project created on the Web-AR.Studio platform [11] featuring an animated 3D model of a heart and additional text information.

This is what has been done so far, but the platform continues to evolve. In the near future, the platform will add surface recognition algorithms and geographic augmented reality, where augmented reality objects appear at specified latitude and longitude coordinates. Additionally, a simplified editor will be added for instant creation of AR projects.

Let's solve the task of analyzing the magnetic field of a physical object using visualization with augmented reality technology, based on the online platform Web-AR.Studio [11].

Problem statement for scientific data analysis:

We have a subject of study - the phenomenon of magnetic field in solenoids. We have the initial data - the presence of two magnetic fields, namely the internal and external fields around the solenoid. We need to obtain analytical judgments about the subject of study, specifically the principles of operation of these magnetic fields in the solenoid, i.e., the directions of action of these magnetic fields. The chosen method to solve this problem in the given context is visualization using augmented reality technology.

After setting the initial data about the magnetic field of the solenoid, we can skip the data filtering stage as it is not required, and proceed directly to the mapping stage. At this stage, three-dimensional geometric objects with corresponding graphical attributes, i.e., the main objects, are assigned to the initial data. The basic functionality of the 3D modeling program "Blender [12]" was used at this stage, where the virtual scene with corresponding three-dimensional geometric objects was created based on typical images of similar processes found in physics textbooks. The next stage is rendering, where we obtain a graphical representation of the mapping results in augmented reality. For this, the three-dimensional models obtained in the previous stage are integrated into augmented reality using the software "Web-AR.Studio [11]". Additional objects are also added to the main objects, and their characteristics are described below the illustration. The process description was taken from the documentation for laboratory work on interacting with solenoids. The three-dimensional model was created using the software "Blender [12]". Text and images were added in the toolbar located in the top left corner of the 2D editor of the Web-AR.Studio platform [11] (see Fig. 9).

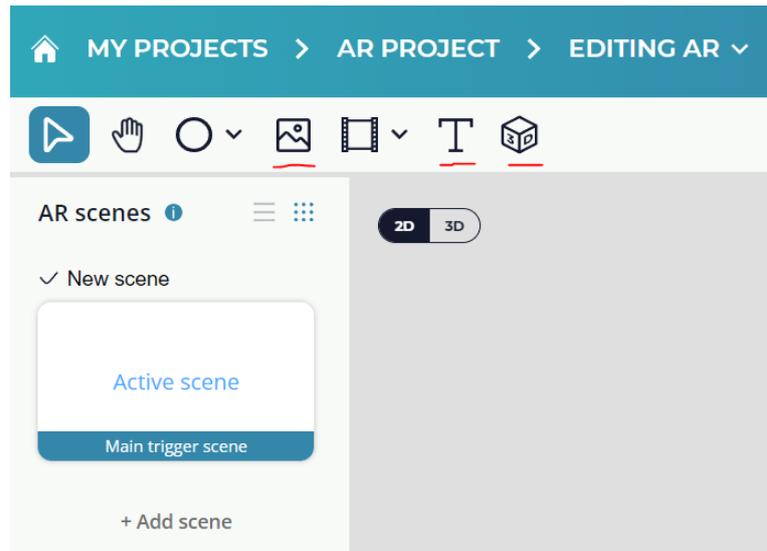


Fig. 9 - Toolbar on the Web-AR.Studio platform [11] with the option to add text, images, and 3D models.

As a result, the resulting scene will be presented as a three-dimensional model with additional objects displayed on the screens of technological devices (such as smartphones, laptops, tablets, etc.), against the backdrop of a working camera (see Fig. 10).

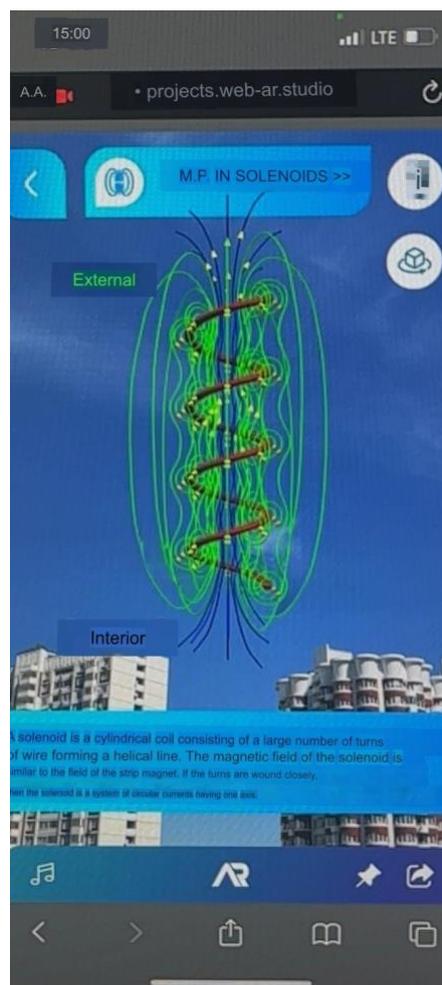
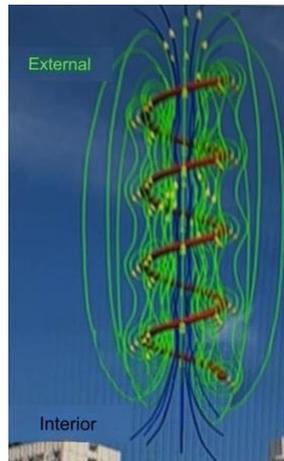


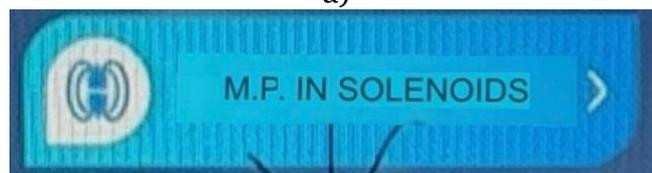
Fig. 10 - Resulting spatial scene in augmented reality, consisting of a main object and additional objects.

The spatial scene represents augmented reality against the backdrop of a working camera on a technological device, and includes the following objects:

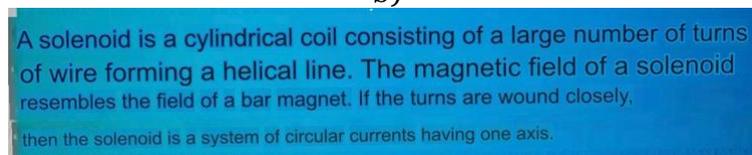
- Main object - an animated 3D model of the process (see Fig. 11 (a)),
- Additional object - auxiliary image with the process name displayed at the top (see Fig. 11 (b)),
- Additional object - auxiliary image with a text description of the process displayed at the bottom (see Fig. 11 (c)),
- Additional object - auxiliary image of an interface for changing the rotation axes (x, y, z) of the 3D model (see Fig.11 (d)),
- Additional object - auxiliary image of an interface for accessing the control instructions (see Fig. 11 (e)),
- Additional object - auxiliary image of an interface for fixing the spatial scene (see Fig. 11 (f)),
- Additional object - auxiliary image of an interface for enabling audio narration of the displayed process (see Fig. 11 (g)),
- Additional object - auxiliary image of an interface for sharing the project with other users (see Fig. 11 (h)),
- Additional object - auxiliary image of an interface for returning to the main scene with the selection of the physical process (see Fig. 11 (i)).



a)



b)



c)



d)



e)



f)



g)



h)



i)

Fig. 11 - Main (a) and additional objects (b), (c), (d), (e), (f), (g), (h), (i) of the resulting spatial scene in augmented reality.

This resulting spatial scene allows for visual analysis of the initial data, specifically the phenomenon of magnetic fields in solenoids.

In this type of project, the resulting spatial scene, which includes the described augmented reality objects, is displayed against the background of the camera image transmitted from the technological device to the analyst. Here, the analyst analyzes the virtual processes generated during the mapping stage, which are constructed in augmented reality during the rendering stage. It is worth noting that in most augmented reality projects, analysts can use their technological devices (such as smartphones) to obtain additional information about a physical object by pointing their device at it and viewing a spatial scene. However, in our project, the virtual objects themselves are the analyzed spatial scene. This scene is animated during the rendering stage and allows the analyst to understand the movement of the magnetic fields (internal and external) and simultaneously receive additional information in text or audio format. It is worth mentioning that for ease of subsequent analysis, the internal and external fields were differentiated by different colors during the mapping stage. The internal magnetic field of the solenoid is represented by the color blue, while the external magnetic field is represented by the color green. This project was created using the online platform Web-AR.Studio [11].

4. Conclusion

During this study, it can be concluded that according to many authors of scientific articles, the optimal applications of augmented reality are in retail and the commercial sector in general. However, the applications of augmented reality go beyond these areas, and one interesting and rational application of this technology is its integration into the data analysis process in visual analytics.

After reviewing the works of leading authors in this field, where they describe models of applying augmented reality to scientific visualization, it can be concluded that this technology is rarely used in scientific visualization due to the difficulty of creating it and the lack of accessible tools for augmented reality creation in the past. The works also present ways to simplify the analysis of spatial scenes for analysts using this technology, such as visualizing scientific knowledge from an open library archive, where augmented reality enhances the informativeness of the spatial scene. This research confirms the benefits of using augmented reality technology for scientific visualization and visual analytics purposes.

The online platform "Web-AR.Studio [11]," which was previously described with an example of its use in educational purposes, is a suitable software tool for creating projects with augmented reality technology that analysts can use for spatial scene analysis.

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