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8 Holography as a progressive revolution in medicine

8.1 Introduction to holographic technology

The first studies about holographic technology can be found in the 1860s by British scientist John Henry Pepper. He developed a technique that we can now describe as a first example of the holographic type. Referred to as the "Pepper's Ghost," it was an illusion technique used in theaters. It relied on the use of two similar-sized rooms, light and a large plate of glass [1]. The audience watched the stage through a plate of glass set at the right angle (similarly to watching the road through cars' front window). A second, hidden, room was placed outside the audiences' field of view but in such a way that it was entirely visible through the plate of glass set on the stage. Properly decreased stage light and increased light in the "hidden" room caused the appearance of reflection on the plate of glass. Objects appearing on the glass were reflections of objects located in the "hidden" room. From the audiences' perspective, they looked like ghost objects standing on the stage (depending on the brightness of light, they've been more/less transparent). Such a technique of showing objects/information in the air/environment where they do not physically exist can be assumed as the basic definition of holography technology.

The first hologram was created in 1947 by Dennis Gabor, who was given the Nobel Prize in 1971 for this. And the first ideas for the use of this technology are noted in the films of the seventies. Lloyd Cross made the first moving hologram recordings, where subsequent frames with an ordinary moving film are applied to the holographic film. Nice-looking examples can be also found in *Star Wars: Episode IV*, where people communicate over very large distances using holographic audio-video connection displayed just in the air. So far, we are still far from making holograms just in the air without any additional displaying devices [2]. Moreover, holograms are used in video games such as *Command & Conquer: Red Alert 2*, *Halo Reach*, and *Crysis 2* [3].

Scientists are still working on obtaining the best quality/resolution of objects, but so far, the best realizations still rely on using glass plates, just like it was first shown by Pepper. Currently, most devices available on the market use a micro-projector (even 10× smaller than those seen in many home cinemas). The picture is displayed on specially developed prism glass (construction is very similar to typically used glasses) and it "stays" there. Depending on the manufacturer, we can find solutions that mainly use one or two glasses and a laser or projectors to display pictures. So far on the market, we can buy simple devices that just display information located statically in one place on the operator glasses, irrelevantly from the

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environment and objects located in the room. More advanced devices combine augmented reality (AR) and holography, where objects/pictures are displayed in a way that they cooperate with the real environment [4].

For example, a 3D designer develops an object on the computer and later displays it on the table in such a way that it pretends to be standing there [5]. One product that combines holography, AR, and portability is the Microsoft HoloLens [6]. This device includes double eye projectors for holography, multiple depth cameras (allows AR to map in a 3D environment and locate object to display in a way that it harmonizes with surroundings), microphone, and speaker for communication (for videoconference use). The entire process of generating objects, environment mapping, and other processing is done by a built-in microcomputer. Thanks to all of the above and a built-in battery, we now have access to powerful holographic glasses that can be used in almost every environment.

8.2 Augmented reality versus virtual reality

Virtual reality (VR) is a medium that can accomplish the embodiment, described by three features: immersion, presence, and interaction. The "immersed in the reality" experience created by computer technology was achieved by the maximum removal of sensations from reality and changing them with the observation from a virtual environment. Presence is a psychological phenomenon crucial to feel as in a virtual environment. Presence determines the level in which people being in a virtual environment react similarly as in the real world, revealing the same behavior and emotional and physiological responses. Therefore, presence is associated with a sense of involvement in the virtual world and being a part of it, which determines the place illusion and the plausibility illusion. These phenomena are related to the interaction, the ability of the computer to detect and respond to user actions in real time by responding appropriately to commands or customizing virtual character responses. Interacting with the virtual environment, even in an unreal way, is the key to a sense of presence.

Virtualization has been defined as "an activity in which man interprets the patterned sensual impression as a stretched object in an environment other than that in which it physically exists" [7]. In the virtual world, the participant is part of the environment, thanks to which head movements cause parallax of movement from the participant's point of view, and reactions related to focusing and tracking of objects are stimulated [8]. In VR, the experiment took place in a simulation that can be similar or completely different from the real world.

The main assumptions of VR are to simulate a place/location/situation for the user, who is not physically in there. For example, a person wearing a special VR helmet can picture himself riding a rollercoaster, whereas in reality, they are comfortably sitting in a chair in the office. The user is disconnected from their environment and only sees the image displayed by the VR helmet (Fig. 8.1). AR is the next technology developed after VR. The first sort of AR device was developed by Ivan Sutherland in 1968 [9], but the term "augmented reality" was first used in 1990 by Thomas Caudell and David Mizell from the Boeing company. In the beginning, the concept of AR is associated with a futuristic vision ever since. AR in some way is an extension of it. What is it? AR is an enhanced version of the physical world through the use of different stimuli such as audio or vision. Digital information is integrated with the user's environment in real-time. Today we are witnessing how it becomes a component of our almost everyday life [10]. AR is divided into three main categories, i.e., markerless AR (location-based, position-based, or GPS), projection-based AR (projects artificial light onto a real-world surface), and superimposition-based AR (it is possible to replace the original view of objects with AR objects).

Fig. 8.1: HTC-Vive-Setup helmet and environment [own source].

AR is some ways a very similar technology; however, using special AR glasses or helmets, in the user still sees their real surrounding environment. It can be compared to using normal glasses. What is new in this technology? AR glasses display the image in a way that harmonizes with the environment. To summarize, VR moved the user into a completely different computer-generated world, such as Oculus Rift [11]. AR applies additional visual elements to the real world, such as Google Glass [12]. Two market-leading solutions are VIVE Pro from HTC [13] and the HoloLens [HoloLens] from Microsoft (Fig. 8.2). In contrast to VIVE Pro, HoloLens is independent and does not require manual controllers. The device is fully integrated with Microsoft Enterprise systems. Its interface is known to users using the Windows operating system on other computer platforms, which makes it easier for users to use it for the first time. The disadvantage of this solution is the fact that the commercial license for HoloLens has a much higher price than VIVE Pro (even taking into account the cost of a workstation computer) [14].

Microsoft HoloLens [6] is the world's first wireless holographic computer. It allows full control over holographic objects, enabling moving, changing their shape, and placing them in the mixed reality space. All equipment is housed in special glasses; no wires or additional devices are needed. For example, a person wearing AR glasses can see an object placed on his desk right in front of him, which physically is not there. Another feature is that AR allows to walk around the desk and watch such an object from different angles when the object is displayed in the glasses in a way that includes the distance of the user from his desk and also angle from which he looks it. In this way, the device can to create a new image each time the user moves, creating an illusion that an object exists in the users' environment without physically being there. A major benefit of AR, compared with VR, is that the user never loses his orientation in the environment where he is (Fig. 8.3).

Fig. 8.2: Microsoft HoloLens—the world's first wireless holographic computer [own source].

Fig. 8.3: Augmented reality glasses can display objects next to the person [own source].

8.3 AR, VR, and holograms for the medical industry

Suddenly, Holograms became a new buzz word when AR was a marketing mantra since 2016. Virtual and AR are immersive technologies that provide new and powerful ways for people to generate, use, and interact with digital information. Currently, every industry wants to see if you can use holograms to get specific benefits. Statista.com predicts that the size of the AR and VR market will increase from USD 27 billion (2018) to 209.2 billion (2022) [15].

Medicine is a discipline that a leader in testing innovative solutions, as well as their regular use in the diagnosis, therapy, and rehabilitation of patients. In this area, the most practical innovation is the application of mixed reality, or a combination of the real image and signals biological data with obtained data, e.g. during the diagnostic process using imaging techniques. AR takes an important role in many medical applications like laparoscopy, endoscopy, or catheterized intervention [16–19]. AR and VR research, once the domain of well-financed private institutions and organizations, is now democratized, and with the terminology.

8.4 Training and mode of action scenarios—medical VR/AR

Clinical staff members responsible for patient care meet with different scenarios in their daily work. Simulating complicated medical situations that require a combination of social, technical, and teamwork skills is a very interesting field in which you can apply AR, among others. These types of solutions can be implemented in the simulation of medical cases as a new form of medical education. New technologies give trainers full design freedom in terms of training scenarios reflecting the real working conditions of medical teams [20]. Currently, many academic centers want to test the possibility of using AR and VR in clinical training. Several important points must be taken into account in the preparation of medical applications in mixed reality:

a. There is a need for very high-resolution medical images, e.g., computed tomography (CT). Besides large 3D data sets (scans) may need to visualize. Can devices such as HoloLens meet these requirements? Videos provided on the Internet are a mix of high-quality images, but they seem to be marketing, in contrast to other, crueler (but more credible) possibilities.
b. Should optically transparent or digitally transparent devices be used? This again leads us to VR wearable devices HoloLens and Google Glass v/s, such as GearVR. At this point, it can compare two devices HoloLens and Google Glass (GearVR). Both have their pluses and minuses. Optically transparent naturally creates a less alienating experience, giving the user the opportunity to see the real world, we still do not know how high the fidelity is and these so-called light points—holographic density compared with the resolution captured images using digital AR solutions.
c. AR and VR have a problem with the delay, which can be less frustrating than the delay with optical visual equipment because the whole "world" will be synchronized with the person.
d. Currently, tests are being carried out on mobile devices, where the delay in updating was noticeable. It was a stress test for the mobile solution Mixed Reality; therefore, the optimization of models and resources is sought.

One of the advantages of the digital transparency of "mixed reality" compared with optical transparency is that the user can seamlessly "travel" between worlds. This is important in a training simulation, for example, if the training aims to take care of the victims in an epidemic or trauma. The simulation of mixed reality can include the following: mannequin placed on a green mat, which is then inserted into the VR world along with the chaos, which would be visible during the first aid medical situation. Such training simulations are most effective in VR. Digital transparency provides the ability to combine AR and VR to achieve a mixed reality. Another example is the administration of a drug to a patient (3D model of AR) imposed on a hospital bed and then a smooth tracking of the course of the drug into the blood vessels of patients and organs.

8.5 Teaching empathy through AR

During education, students reach the point where they have to understand how anatomy is made. Currently, students have a wide range of books, videos, lectures, and seminars from which they can learn. Besides that, during the practical exercises, under the supervision of experienced doctors, students get the possibility to develop their manual skills. Theoretical knowledge is not enough; students must have the well-developed spatial vision to imagine the course. To make it easier to understand and imagine it spatially, the holographic application was created. It was developed to work on Microsoft HoloLens devices. It displays data/application on user glasses in a way that it looks for a user like it would exist in the reality of our environment. The application allows to display 3D objects in a way that they can be rotated, zoom in/out, and also penetrate. Thanks to it, students learn basic pieces of information about the anatomy of pulp chambers and canals in a three-dimensional way.

To better understand holographic technology, it is good to review existing applications that use it. In this chapter, we will review a few different examples of medical applications developed especially for the holographic purpose and Microsoft HoloLens devices.

In 2016, Case Western Reserve University and Cleveland Clinic prepared a HoloAnatomy course (Fig. 8.4) [9]. McDuff and Hurter [21] proposed CardioLens, a mixed reality system using HoloLens, which is real-time, hands-free, and blood visualization from many people's lives. Ortiz-Catalan et al. [22] presented help to a phantom limb pain patient. They designed a new virtual environment in which the patient used his missing arm to use it to perform simple tasks such as lifting and moving small objects. A holographic prototype of the 3D digital anatomy atlas for neuroscience was created in 2016 by Holoxica Limited. Companies such as Medicalholocek.com (Switzerland), CAE Healthcare (USA), Pearson, SphereGen, Digital Pages (Brazil), and MedApp (Poland) use AR, and HoloLens glasses are for training purposes, including the visualization of human anatomy. DICOM Director (USA) enables communication and collaboration between different doctors and medical practitioners.

Fig. 8.4: Viewing objects in three dimensions helps to understand how they really appear. Interactive Commons, Case Western Reserve University, Cleveland Clinic, USA, 2019 [own source].

The application contains a very simple user interface and a very well made guide during the entire process of using the application. In the beginning, the user has to decide where he wants to have the generated model placed. To do that, the user only needs to look at pointing a dot at the right place and use a pointing gesture to confirm his selection. Everything else in the application can be done using voice commands. The application is made in a way that the user is guided through stories prepared by authors. This story/presentation shows a working way of using HoloLens with the human body. It has a few chapters where a guide talks about the human body with different 3D models displayed in holographic technology. Every chapter takes 1–2 min, and when the guide stops talking, the user is left with a holographic model to review/analyze it. To go to the next chapter, the user needs to say "next," and the application generates a new holographic model and talks about it [23]. The biggest benefit of prepared models is that they are done from many smaller objects. When the user approaches the human body, he will be able to see that bones, internal organs, or the circulatory system are separate models.

This is not the end; the user can penetrate the entire body by moving with glasses more into the model. Thanks to that feature, deep organs that are not visible at the beginning because they are covered by bigger organs can be seen. One of the chapters shows the brain with a tumor inside. This is something that for now could be only visible using magnetic resonance imaging (MRI) or computer tomography. In the holographic model, the user could see the entire brain tissue with around 50% of visibility and tumor, which was inside with 100% visibility. In this way, the user could see exactly how the tumor is placed and in which direction it is moving/attacking. It is important to mention at this time that the user can walk around every generated holographic model and watch it from every different direction/angle. For now, this application is used as an educational task. It is used for students of medicine to study the human body and learn it more practically, using holographic technology. Also, holography and AR technology will become the next-generation library.

8.6 Holography in the operating room

What can a combination of medicine and advanced information technology give? It gives breakthrough and revolution in caring for the sick and a completely new era in surgical techniques and imaging. Technologies that we once could see only in sci-fi movies become a reality today, for example, expanded or mixed reality using HoloLens goggles in the operating room. On March 2018, Professor Dariusz Dudek together with a team of doctors from the Jagiellonian University Medical College, Krakow, Poland, conducted the first in Europe treatment of atrial septal defect (ASD) using HoloLens technology in real-time. The treatment took place at the Second Clinical Department of Cardiology and Cardiovascular Interventions at the University Hospital in Krakow. On this day, at the same time, further consultations and treatments were held using innovative hologram-based imaging methods in Nowy Sacz, 100 km away. Thanks to the technology of the Kraków-based MedApp company on HoloLens, Prof. Dudek could connect with the center in Nowy Sącz in real-time for consultation and support on the treatment plan on an ongoing basis. The use of HoloLens and the ability to see a very accurate hologram of the heart revolutionize imaging in cardiology and surgical techniques (Fig. 8.5).

Would not it be great to perform a procedure on an organ (e.g., heart, liver, and teeth) and at the same time have access to an x-ray, CT, ultrasound, or another image, e.g., augmented visualization? Data visualization techniques using AR give us the opportunity to access a dedicated organ. Thus, using AR, it is possible to visually evaluate the external and internal structures of the object (Fig. 8.6). The introduction of this new technique requires the use of properly prepared equipment and dedicated software. The basic equipment is the glasses, which impose a virtual image selected from images on the image seen in real, which were used, for example, in the diagnosis process [24].

Fig. 8.5: Case study—atrial septal defect (ASD). Operator: Professor Dariusz Dudek, Jagiellonian University Medical College, Krakow, 2018 [own source].

Fig. 8.6: Case study—left atrial appendage hologram HoloLens assistance. New Frontiers in Interventional Cardiology Workshops, Krakow, 2018 [own source].

Thanks to the introduction of the latest technologies in the education process, we indicate the path of development in medicine and shape in the students of medicine the desire to enjoy the benefits of new technologies.

In turn, in July 2017, neuroradiology's Wendell Gibby performed an operation on the lumbar region spine using Microsoft HoloLens. To precisely locate the drive that caused back pain, MRI images and CT were loaded to the OpenSight software and then visualized in the 3D image of the spine. After applying HoloLens, the doctor could see the patient's spine superimposed (displayed) like a film on his body. HoloLens tracked the location, to which the doctor watched and navigated the anatomy with more accuracy. Also, Beth Israel Deaconess Medical Center, Visual 3D Medical Science and Technology Development CO. LLC (China) and AP-HP (France) carry out surgical procedures using HoloLens.

The groundbreaking AR/mixed reality technology of the HoloLens reality that allows the visualization of anatomical and pathological structures of patient's organ reflects a modern approach to "tailor-made" patient care, that is, the maximum individualization tailored to a given patient [25, 26].

8.7 Medical holographic applications—our team examples

8.7.1 A wireless heart rate monitor integrated with HoloLens

The HoloLens device made by Microsoft [6] changes the way how we can perceive information, for example, doctor documentation working space. The basic idea of a holographic assistant for a doctor was described in our previous paper [27]. The proposed solution removes almost everything from the doctor's desk. No cables, monitors, or even a mouse or keyboard is needed. Thanks to holographic technology, we receive multiple screens around the doctor's desk. A number of them can be selected in a way that doctors like: one huge screen or maybe four smaller screens with different pieces of information on each of them. Doctors decide what exactly they need at the moment: RTG photo, treatment history, or maybe a schedule of visits to plan the next appointment, everything available just in front of a doctor. High importance information is displayed in front of the doctor to remind about some patient pieces of information, for example, the dangerous reaction for anesthetics, heart problems, or HIV and AIDS sickness when doctors should engage with high caution. The biggest advantage of this way of working is that all of the pieces of information are visible only for the doctor and no one else. The device is secured with a built-in monitor checking if the device was taken off from the doctor's head, which results in blocking access to the application. Another example of holography can be found in Poland, where application and hardware to allow user/doctor monitor patient pulse was developed. The entire idea of the system was to show that thanks to holography and wireless technology, a doctor can watch a patient, read the documentation on the patient's examination and all the time be able to see his pulse value (Fig. 8.7) [27].

During the patient's visit, a wireless heart rate sensor is placed on their finger. The microcomputer connected to that sensor collects data and sends the result to the HoloLens' application started on HoloLens. The entire communication is done over a WiFi connection. The application on HoloLens displays "on-air" actual heart rate value, and information (name) of the patient is exanimated (information is taken from an existing database). The application does not contain any other interface that could limit the field of view for a doctor. This is another big feature where doctors receive additional information without losing their eyeshot.

The entire idea of this solution is aimed to show a way that every patient can be monitored in real-time by a doctor wearing only a holographic device (Fig. 8.8).

Fig. 8.7: A wireless heart rate monitor integrated with HoloLens [29] [own source].

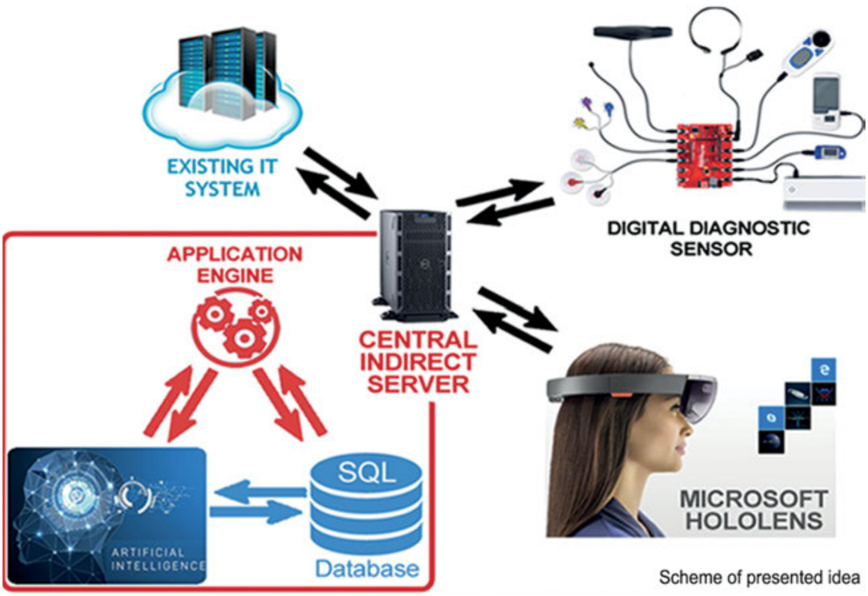

Fig. 8.8: Scheme of digital diagnostic sensor monitor integrated with HoloLens [29] [own source].

A doctor can examine all types of different patient parameters, blood tests, or other results of the examination by having them in front of him. The digitalization of medical documentation is already ongoing. Papers disappear from doctors' desks. The General Data Protection Regulations restricts a way how medical clinics should manage patient documentation in a way that holography is starting to become the best solution for this. The Microsoft HoloLens device restricts what is visible and by who it can be accessed. A doctor can have in front of him many different restricted documents that only he can see.

8.7.2 Holography in stomatology

We tested the feasibility of using HoloLens during carrying out tooth morphology (Fig. 8.9). All people using HoloLens were amazed by the technology and 3D models that they could experience from different angles. Everyone agreed that this is something that could simplify and help during their studies when they had to learn root canals paths.

The created application was done in a few steps. First, 3D models of root canals with different paths where the canals can go were created. It had to include the situation when canals connect, separate, or even change their direction. All of that was done according to Vertucci's classification. The entire work was done using Autodesk Maya, the software typically used to create 3D models for games and animations. When models where done, they were exported to Unity software. It is an application used to create video games and AR software for different devices and systems. A huge benefit of this application is that it also allows creating AR applications

Fig. 8.9: Experimental holographic setup. 3D models of root with different paths of how canals go own [own source].

for the Microsoft HoloLens device. Thanks to it, models created in Maya could be imported to this project. Next, it was required to create separate scripts

- to place models in the exact position in the user-visible area (anchoring models to our environment so they stay in one place),
- to animate action for clicked/selected object (root) in a way that it moved to the middle of the screen and change its size to bigger and start rotating,
- to animate actions for returning the root to its place and mark it as already used/selected, and
- to inform the main management which root was selected so they would know where to put it back.

After testing the application in the Unity emulator, the final step was to export the ready project to Microsoft Visual Studio. This development software is responsible for the final compilation process in a way that application could be installed on the Microsoft HoloLens device.

8.8 Future perspectives: visualization of anatomical structures

The new generation of equipment for displaying holographic objects gives the opportunity to visualize anatomical structures in the form of an interactive three-dimensional image based on scans from classic medical imaging. The visualization of medical data and the ability to view in space, as well as the possibility of cutting anatomical/pathological structures, are reference points for doctors. This is a new innovation in the field of interpretation of medical data. The solution for the visualization of the patient's internal organs, both anatomical and pathological structures, using the latest devices is a reflection of modern technologies used in medicine. The proposed technology leads to the implementation of individualized diagnostics of the latest achievements in data visualization techniques in three dimensions. What will the future bring? We will see. One thing is for sure, holography is on its way to revolutionizing medicine.

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