Funded by
European Union
Civil Protection

APPLICABILITY OF VR/AR/MR SOLUTIONS UNDER THE CONDITIONS OF FRS CR

2021

Funded by
European Union
Civil Protection

Grant agreement no.	831682
Duration of the project	12 months (01/09/2020 – 31/08/2021)
Dissemination level	Public
Status	Final
Annotation	The present report is the output of the "Study of the applicability of VR/AR technologies in the area of civil protection in the Czech Republic", the ambition of which is to implement activities aimed at analytical and synthetic assessment of available technical VR/AR/MR systems and suggest possible implications for the conditions of the Czech Republic, with a focus on the Fire Rescue Service of the Czech Republic.
Keywords	virtual reality, augmented reality, mixed reality, civil protection
Number of pages	104
Number of attachments	0
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The project ***„Study of the applicability of VR/AR technologies in the area of civil protection in the Czech Republic"*** is co-funded by the European Commission Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO), within the framework of the Union Civil Protection Mechanism (UCPM) under the ECHO/SUB/2020/TRACK1 Call (Assistance to Member States for the preparation and implementation of disaster risk management actions - *Track 1*).

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1. INTRODUCTION

Virtual, augmented and mixed reality technologies are becoming pervasive in all areas of human activity. They are no longer predominantly used in the gaming industry only and find increasing use also in areas relating to the management of public assets and provision of public services. Virtual/augmented/mixed reality (hereinafter referred to as "VR/AR/MR") are today's phenomena which are increasingly pervasive in all areas of human activity ranging from the gaming industry through research, medicine to industry. Due to their accessibility, the potential of VR/AR/MR technologies is nearly limitless, but still not fully used. One of the possible areas of application is increasing national security and safety of the population. Although the use of VR/AR/MR technologies is quite common in the defence sector, their use for civil protection and rescue operations is still sporadic. The present report is the output of the "Study of the applicability of VR/AR technologies in the area of civil protection in the Czech Republic", the ambition of which is to implement activities aimed at analytical and synthetic assessment of available technical VR/AR/MR systems and suggest possible implications for the conditions of the Czech Republic, with a focus on the Fire Rescue Service of the Czech Republic (hereinafter referred to as "FRS CR"). FRS CR contributes to safeguarding safety in the Czech Republic by fulfilling and organizing tasks relating to fire protection, civil protection, civil emergency planning, integrated rescue system and crisis management. Due to the broad range of its focus, ensuring continued development of the FRS CR preparedness is a key prerequisite for effective response to all types of emergencies and disasters, including disasters resulting from the current climate change.

The activities carried out by FRS CR are associated with high demands on ensuring safe response in all types of interventions. Due to the nature of interventions, problematic high-risk activities and cost-ineffective activities are excluded from training. The use of VR/AR/MR can therefore be seen as having significant potential to increase the effectiveness of the preparedness of the response units, but significant opportunities can also be identified in relation to the development of the preparedness of the professional public and the population. VR/AR/MR could be used to drill highly specific or high-risk activities or to provide a high-quality psychological and social support after major emergencies as part of PTSD prevention.

While VR is primarily usable in the preparedness process, AR and MR technologies can potentially be used in the stages of prevention (e.g. interactive visualization of map data or safety-relevant sites), preparedness (e.g. staff training) and response (e.g. an intervention helmet visualizing key tactical information using the AR technology).

The project fosters development of a culture of prevention and improvement of cooperation between the civil protection and other relevant services (Article 3(1)(a) of Decision No. 1313/2013/EU of the European Parliament and of the Council) and is directly linked to the fulfilment of the 1st main objective of the call "To support Member States' efforts in enhancing their institutional, technical and financial capacity for preparing, implementing and monitoring strategic disaster prevention and preparedness activities" and the 3rd specific objective of the call "To generate evidence and knowledge on effective disaster and climate resilience for improved policy and practice". The present material serves as a strategic analysis with a potential impact on the overall implementation of these solutions in real national conditions. As the study is publicly accessible, its implicitly expected benefit is sharing of the relevant information across the EU countries.

2. STUDY GOALS AND FOCUS

VR/AR/MR solutions are beneficial because almost anything can be simulated/virtualized by VR/AR/MR applications. Potential applications are therefore limited only by human imagination. Given the rapid development and minimization of HW and SW and increasing affordability, these solutions are experiencing exponential growth in applicability. However, it is still safe to say that they are yet to be fully deployed in the safety and security segment.

This situation has become the starting point for determining the main objective of the present study, which is to:

Assess VR/AR/MR solutions from the point of view of their potential use under the conditions of FRS CR.

Partial objectives, which are also partial steps of the process:

- Description of VR/AR/MR principles and basic hardware and software equipment.
- Definition of the areas of competence of FRS CR offering potential for deployment of VR/AR/MR solutions.
- Identification of potentially usable and commercially available VR/AR/MR solutions, their description and assessment.

Additional information on the focus/limitations of the study:

- The focus is on the agendas of which FRS CR is the guarantor, i.e. the areas of population protection, crisis management, fire protection, integrated rescue system and civil emergency planning. Therefore, it does not necessarily involve only activities directly implemented within FRS CR.
- The ambition is to provide an insight into the issue at hand and to serve as a basic background document for setting the direction for further development. The present document does not therefore serve as a binding strategy for the way forward.
- The fact that the main driving force behind the development of VR/AR/MR solutions is the gaming industry is a key factor contributing to the dynamics of the development of the subject in question. The study therefore presents the key solutions and available findings from the project implementation period, i.e. September 2020 – August 2021. Thus, the existence of commercial solutions that have not been sufficiently published or were only in the design phase at the closing date cannot be excluded.
- The study was not aimed at assessing the possibilities of applying artificial intelligence. The reason is that this is a very extensive topic, the responsible handling of which would go beyond the defined scope of the project. Where AI elements are mentioned in some of the identified VR/AR/MR solutions, it is only because these elements are an integral part of the solutions.
- If, at the time of project preparation, information on the costs associated with the acquisition and subsequent operation of the respective VR/AR/MR solutions was available, such information is provided. The prices are current as of Q1 2021, so it is necessary to reflect the price development of technologies and possible deviations from current market prices cannot be excluded.

3. PREPARATION OF THE STUDY

In order to achieve the stated objective, the following procedure was applied in the course of the study:

- **Description of VR/AR/MR principles and basic HW and SW requirements**

The description and content analysis method was used and comprehensive research in the matter was performed. Relevant Czech and international information sources were reviewed. Empirical methods (questioning) were also used for data collection.

In addition to describing the basic characteristics of VR/AR/MR, the main focus was on the key components of these solutions. Thus, the research covered commercially available computing devices, i.e. the minimum necessary PC standards; display devices, i.e. headset systems; interaction devices, i.e. sensor/interaction devices sensing the position of user body parts, gestures, etc. The following parameters were assessed for these HW components:

- Technical specifications;
- Price.

Basic SW requirements and key input formats were also defined.

- **Definition of the areas of competence of FRS CR offering potential for deployment of VR/AR/MR solutions**

The aim of the above step was to identify agendas in the areas of state administration within the competence of FRS CR offering potential for use of VR/AR/MR tools and thus achieve a qualitative change in the area of prevention, preparedness and response.

In view of the above, these agendas were selected according to the following target groups:

- Members of FRS CR and members of fire protection units;
- Population;
- Professional public.

The primary area of interest is "Members of FRS CR and members of fire protection units".

- **Identification of potentially usable and commercially available VR/AR/MR solutions and their description**

The purpose of this step was to identify comprehensive solutions consisting of HW and SW components that are also potentially usable with respect to the needs/opportunities identified in the previous step. The following parameters were assessed for these solutions:

- Functional description;
- Required HW components;
- Price.

The descriptive method was applied. Empirical methods (questioning) were also used for data collection with respect to individual solutions.

- **Final project outputs**

The last step was the final summarization of the knowledge obtained within the individual steps and its assessment, especially with regard to the assessment of the identified VR/AR/MR solutions in terms of their practical application in the areas of competence of FRS CR.

At this point, mainly explanatory methods were applied, especially the methods of synthesis, analogy and comparison.

The study includes a list of information sources used. The used abbreviations are explained in the text.

4. INTRODUCTION TO VR/AR/MR

4.1 BASIC CHARACTERISTICS OF VR/AR/MR

VR, AR and MR are gaining increasing popularity as they become more and more accessible. The use of these three types of technology is no longer limited to the entertainment industry. They also penetrate areas such as healthcare, education, vocational training, science, sports, civil engineering, defence and other industrial applications. Although VR, AR and MR are all types of immersive technologies (from Latin immersio), they are very different in terms of their technical design and user interface.

There are currently hundreds of practical examples of the use of VR, AR and MR technologies to be found across a wide range of disciplines. Examples selected by Gartner analysts (see the table) indicate a wide range of applications, and in some areas (e.g. consumer AR applications in retail, marketing, publishing) dozens of examples of existing projects using a specific technology can be found online. In other sectors, only a handful of published examples can be found, but the number will grow in the coming years.

Examples of potential deployment of VR/AR/MR solutions are shown in Table 1.

Table 1: *Examples of existing VR/AR/MR deployments (Gartner)*

AREA OF USE	TYPE	COMPANY	VENDOR	BUSINESS OBJECTIVE	SOLUTION DESCRIPTION
Training	AR	GE Aviation	Upskill	Reducing errors in aero engine manufacturing – improving operational efficiency	The Skylight solution, combining AR glasses connected wirelessly with smart tools (real-time measurement and display of tightening torque), has made it possible to refine and speed up the steps required for precise bolt tightening.
Training	VR	ExxonMobil	EON Reality	Utilize new immersive technologies to improve employees' preparedness and work skills in challenging work environments (oil platforms, etc.)	Using an immersive 3D training environment (I3TE technology), employees can learn through virtual activities, improving understanding and memorization of procedures.
Product design and visualization	MR	Ford Motor	Theorem Solutions	Reduce the time needed to design new cars, pick-ups and SUVs, improve collaboration between designers in different remote locations.	The solution allows designers to narrow the "cognitive gap" between the 3D model on the screen and the physical mock-up, make quick changes to models already in production instead of using time-consuming and costly clay mock-ups.

AREA OF USE	TYPE	COMPANY	VENDOR	BUSINESS OBJECTIVE	SOLUTION DESCRIPTION
Product design and visualization	AR	Vodafone	PTC	Assist in the development of new IoT applications/solutions taking advantage of mobile networks.	The Thing Worx platform combines features for rapid application deployment, device management, machine learning and AR – once connected, devices can be analyzed and visualized/viewed in real time
Remote field support	AR	Caterpillar	Scope AR	Save time for technicians during machine maintenance and repair – reduce time needed to consult service manuals on a laptop screen and provide the necessary information continuously during maintenance.	The Scope AR solution displays virtual instructions – a step-by-step maintenance procedure including detailed information on how to perform each task and the subsequent review (safety) steps.
Remote field support	AR	Coca-Cola	Pristine (acquired by Upskill)	Using AR technology for maintenance and repair – displaying procedures and other information so that staff have free hands to work with.	Technicians can use Pristine AR glasses to stream in real time what they see and hear to a remote specialist at a PC anywhere in the world. The specialist can draw instructions directly into the image or display diagrams and procedures from a digital library.
Retail	AR	New Look	Engine Creative	The UK-based clothing retailer was looking for a way to reach a “super-connected” young audience communicating via mobile devices.	A series of AR experiences were created using the Reality Engine platform to interconnect the digital world of the youth with the real world.
Retail	AR	Ikea (2013)	SPACE10	To move away from paper catalogues to applications and offer customers the opportunity to better visualize new pieces of furniture in their own home, thus reducing selection time and the percentage of returned products.	The Place application allows users to place virtual 3D furniture models in the image of their own apartment or house – all on a mobile phone or tablet, whose camera captures the image of the room, and 3D furniture models can be placed, moved or rotated on the display.
Museums/ galleries	MR	Kyoto National Museum	Hakuhodo-VRAR	To create a new and exciting way for visitors to view Japan’s artistic and historical treasures.	The ten-minute “experiential programme” offers a dynamic holographic guided narration for the painted screen by Tawaraya Sōtatsu, “Wind God and Thunder God”.

AREA OF USE	TYPE	COMPANY	VENDOR	BUSINESS OBJECTIVE	SOLUTION DESCRIPTION
Museums/ galleries	AR+VR	Aquarium in Genoa, Italy (2016)	ETT	Use immersive technology to create a more engaging experience and increase visitor numbers/attendance.	ETT developed a mobile application with virtual routes – the Abyss VR room depicting deep-sea life and virtual aquariums where children can create their own fish species.

One of the fast-growing areas of application for these technologies is healthcare. Over the past decade, medical VR applications have developed rapidly and the technology has moved into an area of clinical and commercial importance. Initially, this technology was used e.g. for graphic rendering of anatomy for three-dimensional reconstruction of body organs. Later, it was used in virtual endoscopy techniques based on virtual reconstruction and visualization of patient's anatomy. Today, the use of virtual reality technologies in surgical procedures is part of everyday clinical practice. (Gábor Székely, Richard M Satava, *Virtual reality in medicine* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1129082/)

VR-based systems also offer unique opportunities in aviation. One of the first to expand the use of VR to flight training was Thomas A. Furness III who introduced a working model of his virtual flight simulator to the Air Force in 1982 and is often referred to as a pioneer of VR in this type of research. The UK Ministry of Defence has been using VR in military flight training since the 1980s. In 2012, the United States Army launched a specialized military training system, which is claimed to be the first fully developed military flight training system in VR.

Since pilots often have fewer opportunities for real-world experience, virtual training provides more time to gain experience. Full flight simulation is currently almost indistinguishable from the real world and offers the most realistic flight experience. The flight simulator has become an essential part of civil and military aviation operations.

Similar principles are also used in (not only) truck simulators for specialists such as fire truck operators.

Virtual and augmented reality also has the potential to change many aspects of our everyday lives, including physical security. When ensuring building security, there is no need to search the building and expose persons to danger when an alarm is received. VR/AR glasses can show all the needed information about the building. It is possible to virtually walk, look around and work with information attached to any object or surface or "see through walls". Building managers can use VR technology to visualize network cables, pipes and other equipment hidden behind walls or under floors.

The use of VR/AR/MR solutions is gaining more and more importance, as documented by the rate at which articles on the subject are published according to internationally recognized databases Web of Science and SCOPUS, which cover the high-profile journals in the field (Chart 1). The analysis of publication dynamics below also provides a framework for identifying the leading countries in the field (Chart 2).

Chart 1: *Development in the number of publications focusing on VR/AR/MR – Web of Science and SCOPUS*

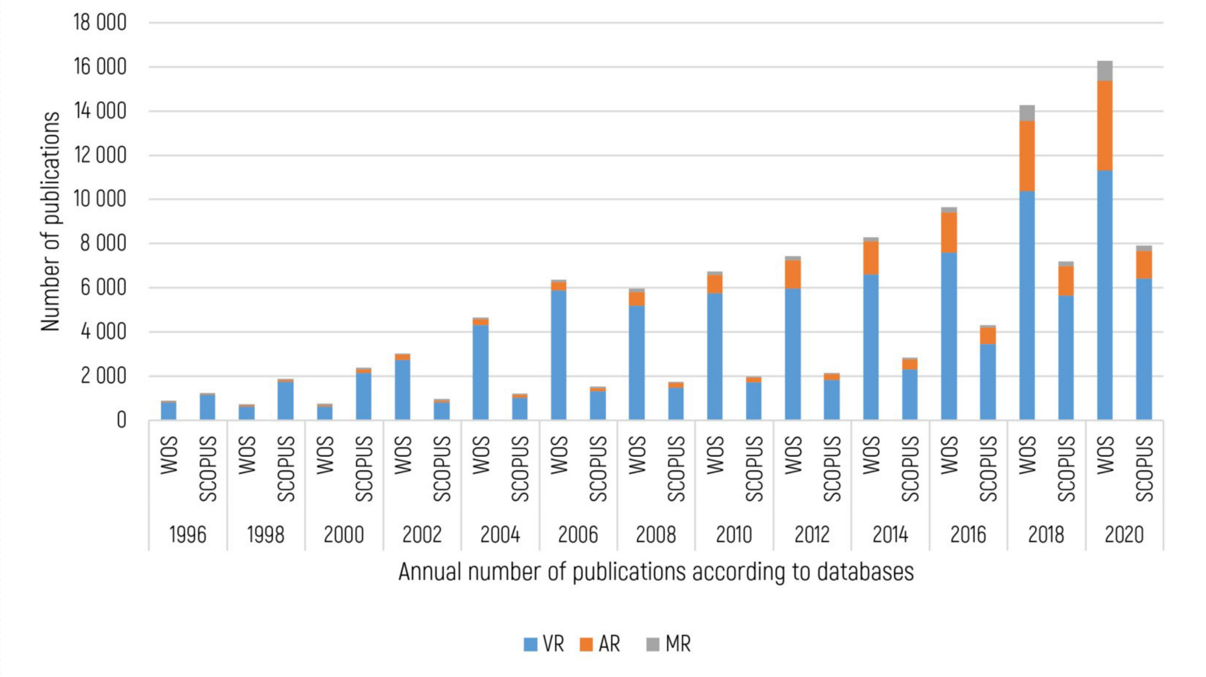
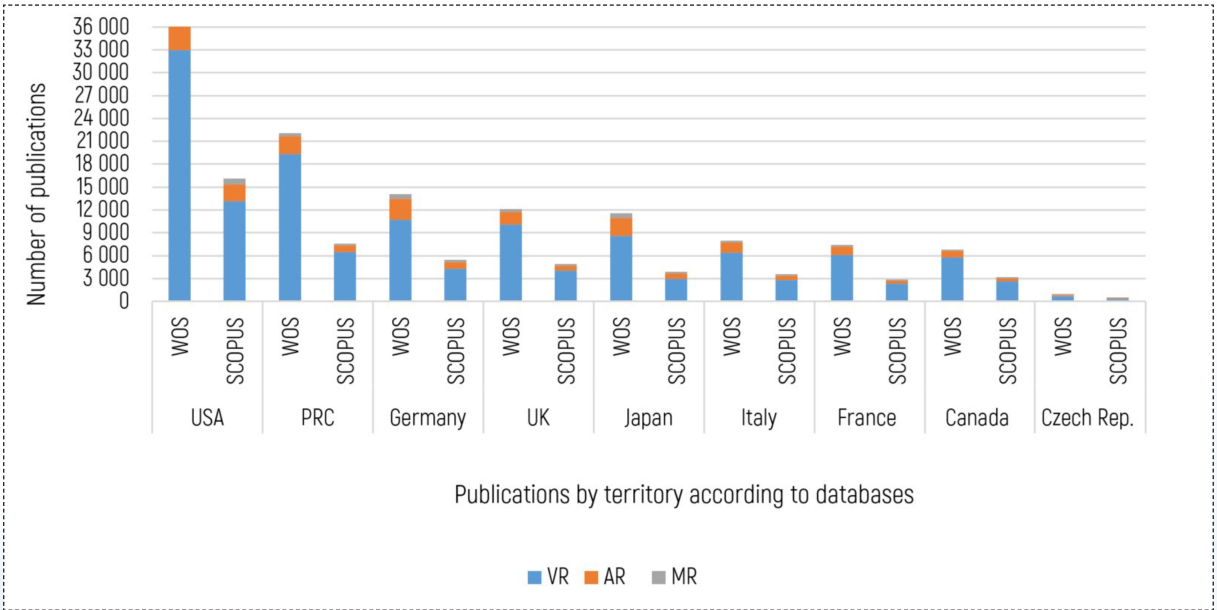


Chart 2: *Publications by country*



4.1.1 VR

The debate about VR technologies started already in the last century. Contemplations about similar systems were linked to the development of computer graphics. At that time, the first devices for interactive graphics were demonstrated. The first helmet display is credited to Ivan Sutherland, who had developed it while still a student at Harvard University in 1968. The device was named the Sword of Damocles which, because of its weight, was suspended from the ceiling on a massive arm used to mechanically sense position and direction. The stereoscopic image was created by two screens placed on the sides to which image was transmitted via simple optics through special glasses to the eyes. This made it possible to observe simple geometric patterns against the background image of the real-world environment.

Since the 1970s, the development of VR has been driven primarily by institutions such as NASA, the US Armed Forces or large corporations willing to bear the large investment costs associated with the development of specialized training centres. Costs of computing and graphics power have long limited the application of VR technologies beyond training astronauts and military or civilian aircraft pilots. A major breakthrough for VR came in 1977 at the Massachusetts Institute of Technology (MIT), where a program was created to simulate a walk through the streets of Aspen, Colorado, USA[1].

The term VR as such was popularized by Jaron Lanier, who founded VPL Research in 1984. This company has come up with several groundbreaking products like the DataGlove (glove with tracking capabilities), the EyePhone (VR headset), AudioSphere (3D audio) and many more. In the late 1990s, the gaming industry began experimenting with VR technology in an effort to commercialize VR for mainstream users[2]. The major boom in VR came after 2010, when the miniaturization and increase in the technology's computing power reached the level adequate for a usable VR headset. Companies like Oculus, HTC and Sony started releasing their headsets and the entire industry began to grow exponentially.

Recently, the term VR has been used primarily to describe a new and very promising field dealing with the use of various modern technical devices for interacting with the computer. This involves a completely new user interface aiming to make the computer environment as close as possible to reality as perceived by our senses. **The user should be as immersed in this environment as possible. The goal therefore is to create a visual, auditory, tactile or other experience (experiments are also conducted with smell and taste) evoking a subjective impression of reality.** For complete isolation from all surrounding disturbances and for full immersion in the virtual environment, **the tools** (devices, aids) that implement such applications in conjunction with the computer **must be** of **high quality**, which includes both audio and visual hardware (i.e., the **headset**, or motion-sensing **clothing** stimulating tactile or other sensation-inducing techniques) and the **computer equipment** (see chapter Hardware and software for VR/AR/MR technologies).

There are three basic categories of VR:

1) Passive applications – providing experience similar to a movie. The users can see, hear, and in some ways even feel the VR environment, but they cannot interact with it in any way (the experience is fully controlled by the software).

Application: *A typical example of such an application is a 3D movie (viewed through 3D glasses) with multi-channel sound screened in a specialized panoramic cinema where the whole auditorium moves to enhance the experience. Teleconferencing can also be included in this category. Several people, each*

1 There were three modes to choose from: summer, winter and polygons. The first two were based on photographs and the third was a three-dimensional model of the city.

2 The first VR product available to mainstream consumers was the Sega VR home gaming console. The technology was not yet mature enough to sufficiently eliminate headaches and vertigo.

of them physically on a different side of the world, share the same room. They can see and hear each other, so nothing prevents them from solving important problems. But they can't move around without restraints or shake hands. There are several major projects focusing on VR Meeting – Oculus Rooms, MeetIn VR, Altspace VR, Rumii.

2) Active application – in this case, the device allows the virtual environment to be explored freely. The users can move around, view the environment from all sides and hear the corresponding sound. However, most of the time there is no tactile feedback, so it is not possible to interact with the environment in any way. The users cannot virtually move objects, open doors, etc.

Application: *In practice, this category can be used to create an experience that may have some therapeutic effect in patients suffering from various phobias (such as fear of heights) or mental disorders. Elsewhere, it can be used to present virtual works of art, to view building designs, in various scientific fields (three-dimensional display of functions of more than two variables) or to train in a real environment using simulators with VR glasses.*

3) Interactive applications – the most sophisticated and also the most technically demanding are fully interactive virtual applications. These allow the environment to be not only explored, but also support interaction. The users can pick up and move virtual objects, work with virtual tools, press various virtual buttons, type on a virtual keyboard, etc.

Application: *One of the interesting applications in this category is virtual surgery, which can be repeatedly performed on a model of a specific patient's organ before the surgeon actually performs it in real life. In the field of civil engineering, one can imagine an architect who can not only view his/her design, but also change it interactively and immediately explore the result from all sides.*

VR therefore has a very wide range of practical applications, even as the technology continues to improve, mainly due to the growth in performance of graphics systems. In 2016, the world's largest manufacturers (StarVR – Acer and Starbreeze Studios, Google, HTC, Oculus, Samsung and Sony) united under an alliance called the Global Virtual Reality Association (GVRA), whose mission is, among other things, to promote VR, unify industry standards and engage in joint development.

4.1.2 AR

AR is a technology that augments real images through computer-generated text, images or video. It is therefore a kind of **digital overlay over the real world**, where we see in real time not only the elements in our field of view, but also virtual objects that we can further manipulate. Unlike VR, which creates an entirely new digital environment and requires the use of a VR headset to explore it, **AR retains the real world and only adds interactive (digital) elements or objects to it.**

The history of AR technology is also closely linked to the training of military and civilian aircraft pilots and was a logical extension of VR development. The first ever fully interactive solution was created in 1992 for US Air Force training purposes. This simulator allowed users to control robots in an environment that contained both real objects and virtual 3D layers. These were added to enhance the user's problem-solving performance. From the simulator rooms, AR moved to the displays on the fighter jet cockpit head-up screens and pilots' helmets, allowing them to view important data without having to tilt their heads and refocus on the instrument panel. From about the 1980s onwards, the technology began to find application in the field of civil aviation, and from this technological sphere it gradually spread into other areas. In 1994, AR technology was first used in a theatrical production called Dancing in Cyberspace, in which performers danced on stage around virtual objects. Then, in 1998, the technology was introduced to the US TV viewers during a broadcast of an American football game when the technology was used to visualize the line where the attacking team must advance in an attempt to cover a 10-yard distance.

AR technology found another commercial application in advertising in 2008, when a German carmaker developed a printed advertising magazine for the BMW Mini model. By scanning the magazine using a computer camera, the model was mirrored on the computer screen and the user controlled the movement of the displayed image by manipulating the magazine. Other cases of use in advertising followed, e.g. in 2011 National Geographic used the technology to simulate extinct animals walking in a shopping mall, or in 2013 Coca-Cola simulated melting ice on the Earth's poles in a shopping mall. The global success of the mobile game Pokemon GO in 2016 was the most recent time that this technology came to public awareness. Towards the end of the decade, the fashion industry began experimenting with the technology. The ASOS application shows customers fashion models wearing the clothes they are currently browsing, or shoe-maker Gucci's application allows customers to see how the shoes they choose would look on their feet. Similarly, since 2017, the IKEA Place application has been available, allowing customers to view a realistic model of the product of their choice in their own home.

In practice, the use of AR is based on the camera taking a picture of the surrounding environment, using sensors to record the exact location or orientation of the device and then displaying digital objects on the screen. The whole principle could be summarized as follows: 1) We launch an application which turns on the camera, thanks to which we can see the image over which the AR objects will be overlayed; 2) the hardware (sensors) and the software analyze the environment in real time; 3) several complex mathematical calculations are performed; 4) virtual objects are displayed on the screen. It is therefore necessary to determine in advance which point or object the device (e.g. smartphone) will respond to. In other words, to determine the stimulus that the AR application will wait for. This point can be our face, a QR code or a specific object (e.g. a building).

The above shows that **AR applications have high requirements on computing power**. Therefore, they usually **use cloud solutions**. In addition, to function properly, **they need** the aforementioned sensors, such as: **accelerometer** (device orientation detection); **gyroscope** (tilt or rotation detection); **GPS** (position detection); **depth camera** (object capturing and recognition); **camera**.

Three options can be used to display AR:

1) Head-mounted display, e.g. glasses – virtual objects are projected in front of the eyes. The AR elements can only be perceived by the user wearing the glasses. *Their use can be found e.g. in product quality control, where the inspector can quickly and efficiently evaluate the success of the production process. These special glasses are offered e.g. by Microsoft (HoloLens glasses), Acer (Acer Mixed Reality Headset) or Google (Google Glass).*

2) Projection – several appropriately placed projectors are needed to project virtual objects onto real ones. Unlike the display, it is therefore useful in situations where a large number of people work with AR. *It can be used e.g. during reconstruction of buildings, where a new design can be displayed on the original site. This allows us to immediately see how the reconstructed building will look like in the context of its surroundings.*

3) Mobile phone display – this is the most affordable option, used in combination with an AR application or game, or a web application using WEbAR and a web browser.

AR applications can be divided into several categories according to the way they connect to the real world:

- **Marker-based applications** where the camera scans its surroundings and once it detects a pre-determined object (marker), it plays the desired animation, sound or video. The object can be e.g. a QR code, a special tag or an object. The animation can be static or dynamic – a standing figure that speaks or a figure that moves around.
- **Markerless applications** are based on position information. The display of the virtual elements depends on the user's current location. An example of this is the Wikitude application, which displays related information when you point the camera at an object. The application can be used on trips to learn interesting facts about historical monuments. Horizon Explorer works in a similar way, showing altitude information and a map with directions how to reach a building.
- **AR applications using projection on different surfaces (projection-based) and tools that can replace the original object with a virtual one (superimposition-based).** *A great example is the Ikea Place app, which makes it easy to try out how furniture from the Swedish manufacturer's catalogue would look like in the user's home.*

It can be said that AR is the most used type among all types of VR nowadays. The main reason why AR is more popular is that compared to VR, you don't need a lot of computing power to use it, and to create AR, all you need is a smartphone, which almost everyone has nowadays.

4.1.3 MR

MR is a combination of the real and digital worlds. In mixed reality, digital information is represented by holograms (objects made up of light and sound) that appear in the space around you. Through artificial intelligence, these holograms respond to commands and interact with real-world surfaces in real time (user input comes in a variety of ways, including keyboard, mouse, touch, ink, voice, or Kinect technology). The result is a more natural and intuitive environment. The main difference between MR and AR is the overall representation of virtual objects in the real environment and their believability by the user. While AR based on overlaying the environment places virtual objects anywhere in space so that they overlay all real objects and can "levitate" in the air, **objects created by MR pretend to actually be part of the real-world environment**. The computing power required to process the data is also very different. While a smartphone is enough to create AR, **MR requires more computing power**.

Mixed reality, as the youngest of the technologies in question, is one of the most dynamically developing areas. For example, Case Western Reserve University in Cleveland has been using MR to teach realistic human anatomy since 2015. Similarly, the implementation of BAE's MR technology has helped speed up battery production time by 40%. Since 2016, this computing power-intensive technology has been used to a certain extent by the gaming industry, e.g. Arizona Sunshine, Form or Space Pirate Trainer.

To create a true MR experience, a combination of computer equipment, user input and real-world data collection is required. Without the collection of data from the real environment (e.g. the exact location/position of a person – using head tracking, the surface and boundaries of the environment – spatial mapping, lighting, sounds, object recognition and location), the interconnection of the two realities would not be as convincing. This interconnection that links the real world with the digital world is called the **MR spectrum**. Today's devices are only able to support certain ranges of the MR spectrum. However, it is expected that in the future the spectrum covered will increasingly expand – holographic devices will incorporate the technology used in "immersive" devices and vice versa.

One of the leading companies that would like to make MR available to all its users is Microsoft. In Windows 10, a core MR platform is already available (for both manufacturers and developers) that allows the digital representation of people, places and things to blend with the real environment. There are two types of devices that can be used to test the MR in Windows 10:

1) Holographic devices – these devices are characterized by the ability of the device to embed digital content (objects) into the real environment as if it were there.

2) Immersive devices – these devices are characterized by the ability of the device to create a sense of reality – they block out real objects and replace them with digital objects.

Application: *In practice, MR can be used e.g. in manufacturing processes which share many similar aspects. The complex design, construction, and maintenance of machines in architecture, mechanical and civil engineering offer opportunities for the use and expansion of MR technologies, as high expertise and large amounts of technical documentation and information are required. In this case, MR technologies are expected to bring essential digitally-processed information directly into the user's field of view while they perform work, thus making it easier.*

The designer's work starts with the creation of a completely digital model that matches the real model, a "digital twin". **Accuracy** is one of the most important aspects when it comes to 3D models that are supposed to overlay real models. The digital model must also fit the real model exactly in a 1:1 ratio. In these cases, **the key is** the **quality of the camera on the device** used for MR. It must be **powerful enough** to keep up with and correctly capture the user's position and the angle at which he/she is looking at the model and at which the model is being captured.

Digital models can also be used for various repairs, where the finished product needs to be disassembled and then put back together again. The instructions might include displaying of disassembly and repair instructions, which the user would be able to see while working when using Microsoft HoloLens. When combined with the Trimble Connect app (https://trimbleconnect.cz/), Microsoft HoloLens could also be used during construction works. For example, life size 3D models could be used to quickly and easily determine the location of reinforcements, identify potential collisions and better coordinate the entire construction process. Thanks to the fact that the user can see the model overlaid over the surrounding real-world environment, this technology meets even the most stringent safety requirements.

MR therefore has the potential to completely change the way we work in these areas today. However, to be able to fully use MR technologies in other areas, it is necessary to first specify the tasks for which they could be used and then modify them for these tasks. In addition, the ever-increasing performance of hardware and other systems, such as those used for location and movement tracking, motivates us to explore further possibilities and improve and develop MR technologies.

4.2 HARDWARE AND SOFTWARE FOR VR/AR/MR TECHNOLOGIES

4.2.1 HARDWARE

In order for VR, MR and AR technologies to work properly, the following equipment is required:

- **Computing equipment;**
- **Display device;**
- **Interaction devices.**

A system composed of these elements then creates a virtual environment at the desired level. Smartphones can also be used for virtualization. Although a smartphone can be used for both VR display and computing, the results can be noticeably worse, in particular with some models and for certain uses, than when using display devices connected to a workstation.

A) Computing equipment

To ensure seamless performance of display devices, in this case **Oculus Rift, HTC Vive and Windows Mixed Reality VR headsets**, the manufacturers provide r**ecommended hardware specifications** for workstations. The specifications required for display devices are almost identical. Most of these manufacturers also offer applications (such as Oculus Compatibility Check, SteamVR Performance Test, or Windows Mixed Reality PC Check) that automatically check the user's computer specifications against their recommendations.

The required HW configuration needed for each display device is shown in Table 2.

Table 2: *Requirements for computing equipment*

DISPLAY DEVICE	COMPUTING EQUIPMENT HW REQUIREMENTS			
	VIDEO OUT/USB/OS	GRAPHIC CARD	CPU	RAM
(GB)	HDMI 1.3, 3x USB 3.0,WIN10	NVIDIA GTX 1060 / AMD Radeon RX 480 nebo vyšší	Intel i5-4590	8
Oculus Rift	HDMI 1.3, 3x USB 3.0, WIN10	NVIDIA GTX 1060 / AMD Radeon RX 480 or higher	Intel i5-4590	8
Valve/SteamVR/HTC Vive	HDMI 1.4, 2x USB 3.0, WIN10	NVIDIA GTX 1060 / AMD Radeon RX 480	Intel i5-4590 / AMD FX 8350	4
HTC Vive Pro	HDMI 1.4, 2x USB 3.0, WIN10	NVIDIA GeForce GTX 1070, Quadro P5000, AMD Radeon Vega 56	Intel i5-4590 / AMD FX 8350	4
Windows Mixed Reality Ultra PCs	HDMI 2.0/Display Port, USB 3.0, WIN10, 90 fps	NVIDIA GTX 960/1050, DX12, AMD RX 460/560, DX12	Intel Core i5 4590, quad-core, AMD Ryzen 5 1400 3.4 GHz, quad-core	8 DDR3
Windows Mixed Reality PCs	HDMI 1.4/Display Port, USB 3.0, WIN10, 60 fps	Integrated Intel HD Graphics 620 (or better) DX12, NVIDIA MX150/965M (or higher), DX12	Intel Core i5 7200U, dual-core with Intel Hyper-Threading Technology enabled	8 DDR3
Pimax 5K and 8K	Display Port, USB 3.0, WIN10, 60 fps	NVIDIA GTX 1070 or better (5K series), NVIDIA GTX 1080Ti or better (8K headset)	Intel i5 equivalent	8

B) Display device

A device that allows the user to view VR image using displays. These are VR/AR/MR headsets consisting of a device frame that is fitted with displays that project a separate image from the virtual environment for each eye. The frame of the glasses is also equipped with sensors that track both eye and head movement to ensure that the displayed image accurately reflects the movement of the user's head and eyes.

A summary overview of display devices is shown in Table 3.

Table 3: *Přehled zobrazovacích zařízení*

REALITY TYPE	DISPLAY DEVICE
VR	HTC VIVE
	HTC VIVE PRO
	HTC VIVE COSMOS
	HTC VIVE FOCUS
	OCULUS RIFT S
	OCULUS QUEST 2
	HP REVERB G2 OMNICEPT EDITION
	PICO GOBLIN 2
	PICO NEO 2
	TOPSKY F7X V2 FPV
	ACER WINDOWS MIXED REALITY HEADSET OJO 500
	PIMAX 4K
AR	C-THRU
	HELON 360
	KC WEARABLE
	FUSION VISION SYSTEM
	NEXTVISION
	VUZIX BLADE
	MOVERION BT - 300
	GOOGLE GLASS ENTERPRISE 2
	TOSHIBA DYNAEDGE AR 100
	SOLOS SMART GLASS
	eMACULA
MR	MAGIC LEAP
	MICROSOFT HOLOLENS 2
	THIRDEYE X2MIXED REALITY GLASSES
	EVERYSIGHT RAPTOR

VR HEADSETS

HTC VIVE

The basic version of a display device from HTC. The device is equipped with two LCD displays with a total resolution of 1080 × 1200 px (2160 × 1200 per eye), a 90 Hz refresh rate and a 110 degree field of view. The claimed battery life is 6 hours.

Price: approx. EUR 650 (approx. CZK 17,000).

Figure 1 - *HTC VIVE*

Figure 2 - *HTC VIVE controller*

HTC VIVE PRO

Virtual reality headset. The device is equipped with two LCD displays with a total resolution of 2880 × 1600 px (1440 × 1600 per eye), a 90 Hz refresh rate and a 110-degree field of view. The device is equipped with two microphones and a dual camera that ensure higher-quality capturing of the outside world, and an integrated headset with positional sound and localization.

Price: starting at EUR 679 (approx. CZK 18,000).

Figure 3 - *HTC VIVE PRO (full HW) set*

HTC VIVE COSMOS

HVirtual reality headset. The device is equipped with two LCD displays with a total resolution of 2880 × 1700 px (1440 × 1700 per eye), a 90 Hz refresh rate and a 110-degree field of view. The headset includes an integrated microphone and headphones. It is equipped with a 6DoF system – i.e. the device supports six degrees of freedom of movement within the 3D environment (as opposed to the older 3DoF standard) and this feature is enabled by 6 cameras. The device packaging includes 2 controllers and additional equipment (cables, batteries, charger, etc.).

Price: USD 699 or USD 900 for the Elite version (CZK 15,500 or CZK 20,000).

Figure 4 - *HTC VIVE COSMOS*

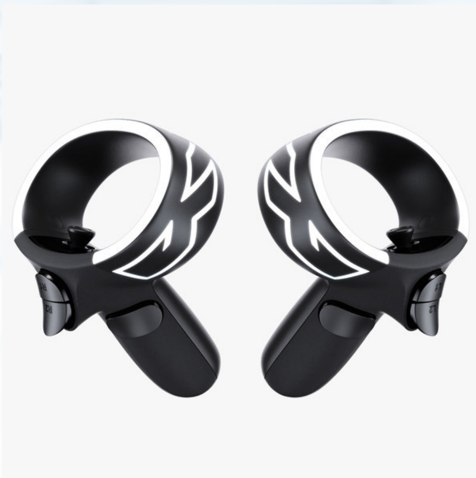


Figure 5 - *HTC VIVE COSMOS - controllers*

HTC VIVE FOCUS

Autonomous virtual reality headset. This device uses the Android operating system supported by the Google DayDream platform. It is equipped with a 6DoF system – i.e. the device provides six degrees of freedom of movement within the 3D environment (as opposed to the older 3DoF standard). The device is equipped with two displays with a resolution of 2880 × 1600 px (3K resolution), a microSD card slot and wireless wifi connectivity. The integrated battery life claimed by the manufacturer is up to 3 hours. A small wireless remote control is also included for seamless control of applications.

Price: starting from USD 599 (approx. CZK 13,000).

Figure 6 - *HTC VIVE FOCUS*

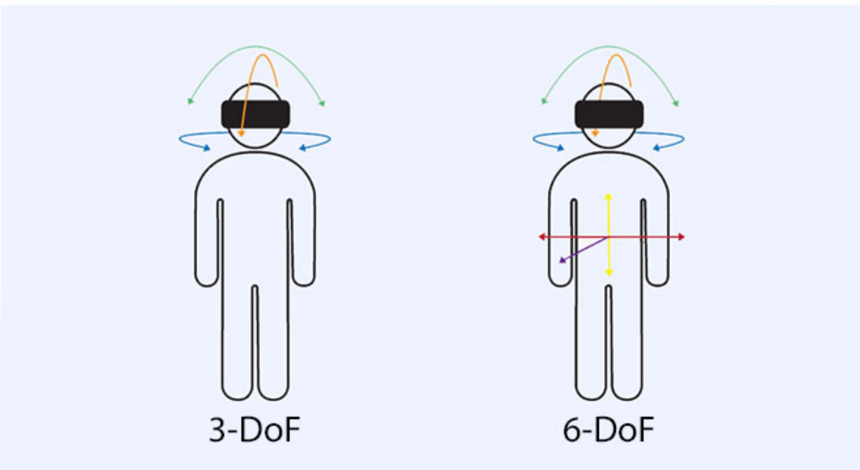


Figure 7 - *HTC VIVE FOCUS – comparison between 3-DoF and 6-DoF versions*

OCULUS RIFT S

A VR headset that uses the computational power of a computer (connected via USB 3.0). This device is equipped with displays with a total resolution of 2560 × 1440 px and a refresh rate of 80 Hz. The product comes with 2 controllers and additional equipment. It supports 6DoF and uses 5 integrated cameras. The device supports positional audio that is integrated directly into the headset.

Price: USD 399 (approx. CZK 9,000).

Figure 8 - *OCULUS RIFT S*

OCULUS QUEST 2

Autonomous VR headset. This device has two screens with a refresh rate of up to 90 Hz and a resolution of 1920 × 1832 px (total 3840 × 1832 px). It is powered by the Qualcomm Snapdragon XR2 platform and has 6 GB of RAM. The basic model comes with 64 GB of storage; however, there are higher versions available offering up to 256 GB of storage. According to available information, Oculus Quest can only be used with a Facebook account; the operating system (based on Android) and the device software cannot be operated without logging into the device with a Facebook account.

Price: starting from USD 299 (approx. CZK 6,600).

Figure 9 - *Oculus Quest 2 with controllers*

HP REVERB G2 OMNICEPT EDITION

In development. A display device that includes sensors capturing selected data (gaze, pupil size, pulse, facial expression) and evaluating the user's mental activity when performing tasks. The resolution of the displays is 2160 × 2160 per eye.

Price: Unknown.

Figure 10 - *HP Reverb Virtual Reality Headset – G2 Omnicept Edition*

PICO GOBLIN 2

Autonomous virtual reality display device with integrated headphones. The device supports 3DoF technology. It has two displays with 4K resolution (3840 × 2160 px in total), a 75 Hz refresh rate and 32 GB of storage. No external PC or other external device is required.

Price: approx. EUR 350 (approx. CZK 9,200).

Figure 11 - *Pico Goblin 2*

Figure 12 - *Pico Goblin 2 with a controller*

PICO NEO 2

Autonomous virtual reality display device with integrated headphones. It supports 6DoF and is equipped with two displays (with 1440 × 1600 px resolution for each eye), a 90 Hz refresh rate, a 101-degree field of view and a slot for a microSD card up to 256 GB. No external PC or other external device is required.

Price: starting from EUR 350 (approx. CZK 9,200).

Figure 13 - *Pico Neo 2 with controllers*

TOPSKY F7X V2 FPV

Display device designed primarily for flying drones, where the user can see the first person view of the "pilot" without being distracted by his/her surroundings. The goggles feature two separate displays, each with a resolution of 1280 × 720 pixels. The field of view is 42 degrees. Using a HDMI connector, these goggles can be connected to any device with a HDMI output.

Price: around USD 500 (approx. CZK 11,000).

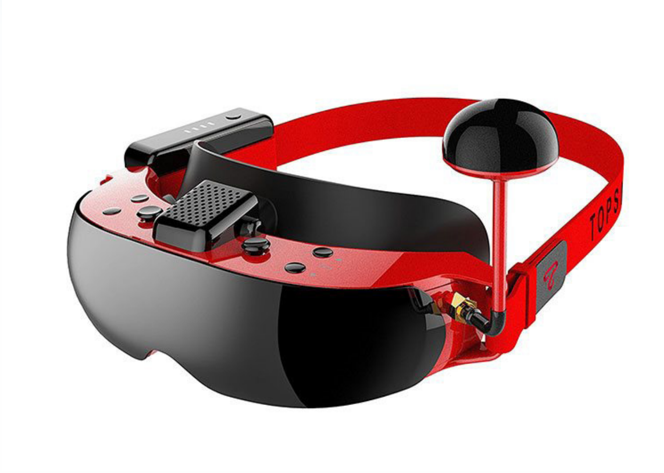


Figure 14 - *Topsky F7X V2 FPV*

Figure 15 - *Topsky F7X V2 FPV – in-flight display*

Acer Windows Mixed Reality Headset OJO 500

Acer OJO 500 is a modular product with removable components. It is designed for businesses, museums, educational and training centres, as well as for gaming centres. The headset, lens and head strap can be completely removed and cleaned. In addition, the modular design allows the device to be adapted to a specific user (e.g. eye distance, forehead height, etc.).

The optical portion of the headset can be flipped up – the user doesn't need to take off the whole headset to see the real-world environment. The device offers a 100 degree field of view and features two 2.89-inch LCD displays (with a resolution of 2880 x 1440 pixels) with a refresh rate of 90 Hz. The device has integrated sound which eliminates the need for separate headphones (however, headphones can still be connected).

Price: approx. CZK 16,000.

Figure 16 - *Acer Windows MR OJO 500*

AR HEADSETY

C-THRU

QWAKE technologies has introduced an innovative use of augmented reality to navigate FPUs in smoky areas during interventions where zero visibility makes orientation difficult for firefighters. With the help of sensors mounted to a special helmet that scan the surrounding environment, the user can see the detected outlines of rooms and objects on the helmet display together with directional information on how to move around in the area. This allows firefighters to walk through smoky areas when rescuing persons or fighting fires inside buildings. The application supports streaming and recording of the information captured by the helmet sensors, which can be conveyed to the response commander's tablet. Thus, in conjunction with 5G localization of the responders, the commander gets a comprehensive situational overview and can provide instructions on how to best move in the affected zone or the information can be used for evaluating the intervention later on.

The device collects on-site data in real time via a thermal imaging camera. The data is sent to a computer where a 3D image is computed based on rendering algorithms. After the calculation, the information is sent back to the helmet user where it is displayed as a 3D image. The outlines of the interior of buildings, the objects inside them and the people inside them can thus be identified.

The data is stored and can be later used for further evaluation of the intervention and potentially also for training.

The hardware consists of a minicomputer and a display device.

Price: Unknown.

Figure 17 - *C-THRU*

A design concept of a smart firefighter helmet with 360-degree temperature sensing that allows both navigation in the intervention area and display of notifications and instructions from the intervention commander, to whom the data from the camera is simultaneously streamed.

Price: Not specified yet.

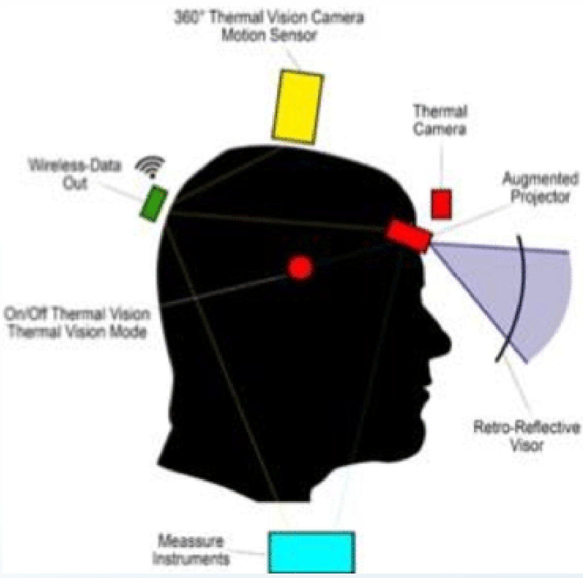


Figure 18 - *Helos 360 - design concept*

KC WEARABLE

KC WEARABLE has developed an augmented reality helmet that can measure the temperature of surrounding objects, scan and assign QR codes and recognize faces and license plates

The device can measure temperature in two modes. These include a large-crowd temperature measurement mode and a single-person temperature measurement mode.

Price: The purchase price is around USD 6,680 (about CZK 150,000).

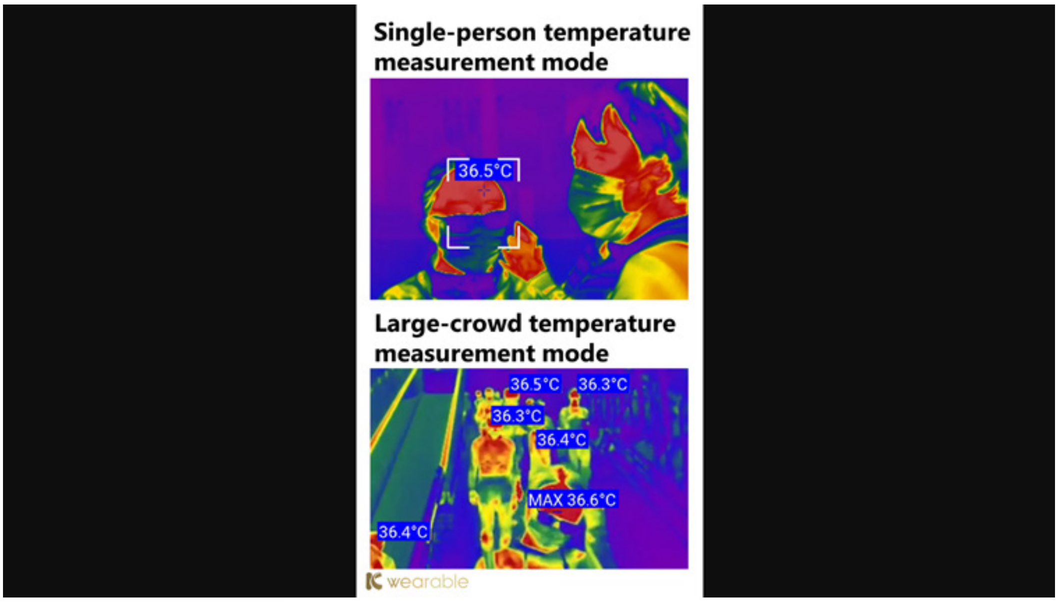


Figure 19 - *KC WEARABLE - temperature imaging*

FUSION VISION SYSTEM

This is an augmented reality device that is still in development. Only a prototype has been presented so far and the exact hardware and software specifications are therefore unknown.

The device is intended to provide improved vision in low visibility conditions, enable more effective information sharing, serve as an aid during search and rescue operations and help locate fire outbreaks.

It will be possible to attach this device to a helmet to display images captured by a thermal imaging camera. It will also be possible to transmit images captured by the camera to a remote computer (e.g. to the intervention commander).

It is expected that the device will use artificial intelligence to highlight people in the displayed image, detect the outlines of walls and objects, monitor the environment (temperature, air pressure, humidity, etc.) and help locate fire outbreaks.

The device is designed to better address the four aspects which are currently considered critical for a successful firefighting intervention:

- Poor visibility (smoky areas, difficulties in finding people during search and rescue);
- Loss of spatial orientation (poor ability to navigate in smoky areas, risk of separation from the rest of the intervening unit, delay in progress towards the designated location);
- Hidden fire (not every fire is visible to the eye, invisible fires are extremely dangerous);
- Limited communication (limited radio communication, no visual information)

The developer is collaborating with several fire departments in Canada.

Price: Not specified yet.

Figure 20 - *Fusion Vision System device prototype*

Figure 21 - *Device visualization*

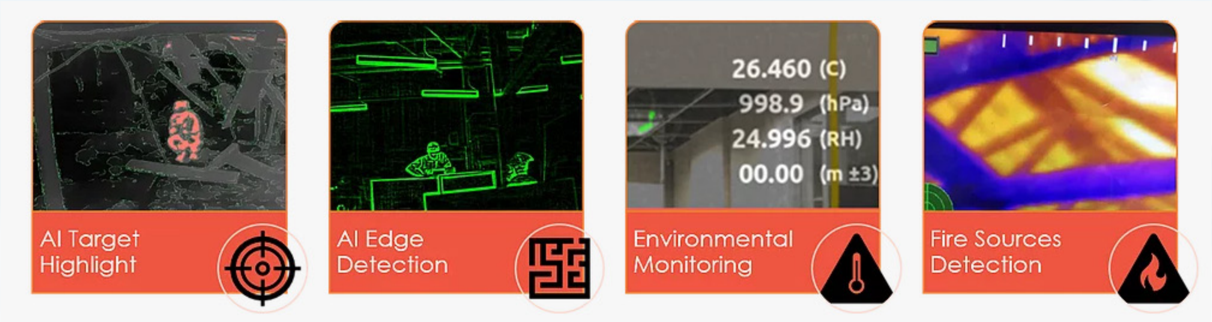


Figure 22 - *Example of the intended functions of the Fusion Vision System*

NEXTVISION

This device is currently under development and there is not much information available about it yet. It is supposed to be a digital AR night vision system intended primarily for special armed forces units.

The device should offer high resolution, a large field of view and operation in deep darkness (NATO level 5 – "deep dark").

Another planned major feature is the option of marking people with symbols and distinguishing them from others (in the planned version for the armed forces, this is to distinguish friendly units from enemy targets). It is unclear how exactly this technology is supposed to work (whether it would use AI-assisted recognition or, for example, peer-to-peer sharing of location data from other friendly users to subsequently mark others as potential enemies).

Price: Not specified yet.

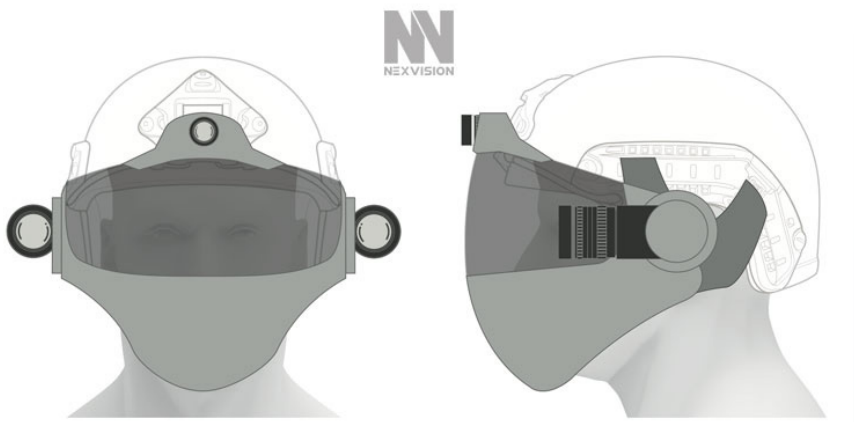


Figure 23 - *Night vision goggles from Nextvision – drawing*

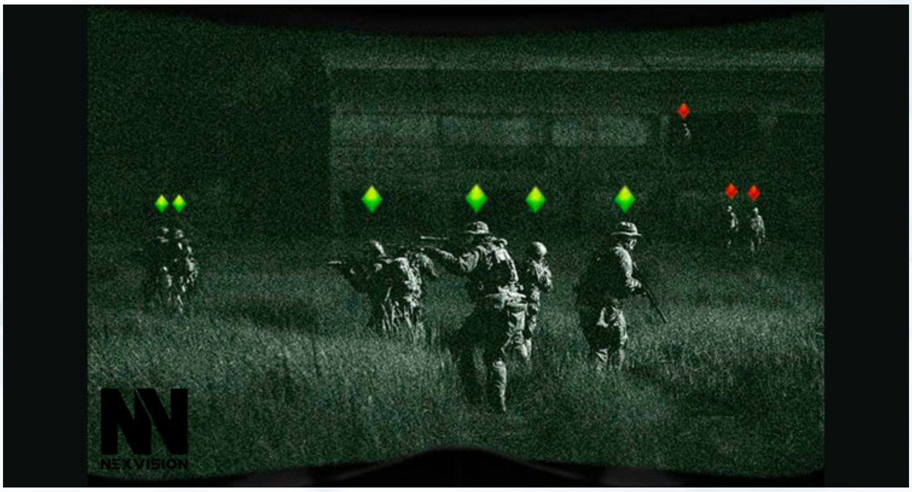


Figure 24 - *Marking of people on the captured image with symbols*

VUZIX BLADE

These augmented reality glasses do not require connection to an external computing unit.

The glasses use the Android operating system by default (however, iOS can also be used) and are primarily controlled by a side touchpad. Currently, the official software to support the device is only available in English and Japanese.

The resolution of the displayed image is 480 × 853 px (i.e. it is even lower than HD resolution), however, given that the image is displayed only "on one glass" near the eye, the lower resolution is understandable.

The device is equipped with an 8 megapixel camera that supports recording of HD videos at 30 fps or FullHD videos at 24 fps. The glasses have an integrated microphone and sound.

The basic storage is less than 6 GB. The glasses are equipped with a microSD card slot (the storage capacity can thus be increased by up to 32 GB), wifi and Bluetooth connectivity and a micro USD connector. The device is powered by a LiPo (lithium-polymer) battery with a capacity of 470 mAh. The claimed battery life per one charge ranges from 35 minutes to several hours, depending on the intensity of the activities performed. For example, shooting videos drains the battery the fastest (the battery lasts for about 35 minutes), watching movies raises battery life to about 2 hours, and using simpler applications drains the battery less and allows for longer operation. The device weighs less than 100 grams.

The primary purposes of the device are to display information about the surrounding environment, collect data, support remote audio and video communication and more.

Due to its nature, the device cannot be used with prescription glasses.

The manufacturer warns that the glasses should not be exposed to excessively humid environments. This could limit FRS CR's use of the device to only certain premises and for certain activities.

Price: USD 1,000 (approx. CZK 22,500).

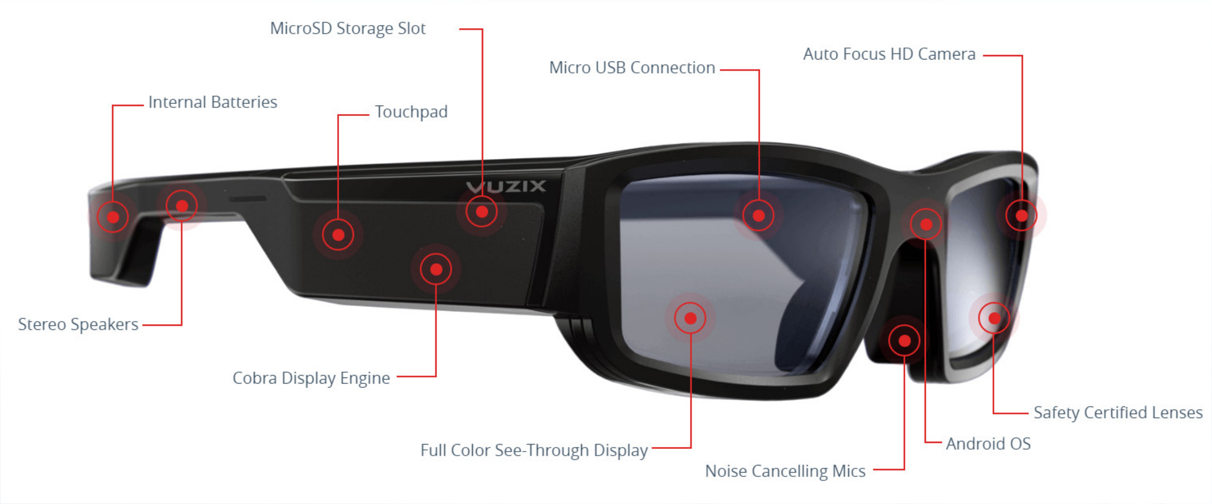


Figure 25 - *Illustration of the main components of Vuzix Blade glasses*

Figure 26 - *User with Vuzix Blade glasses*

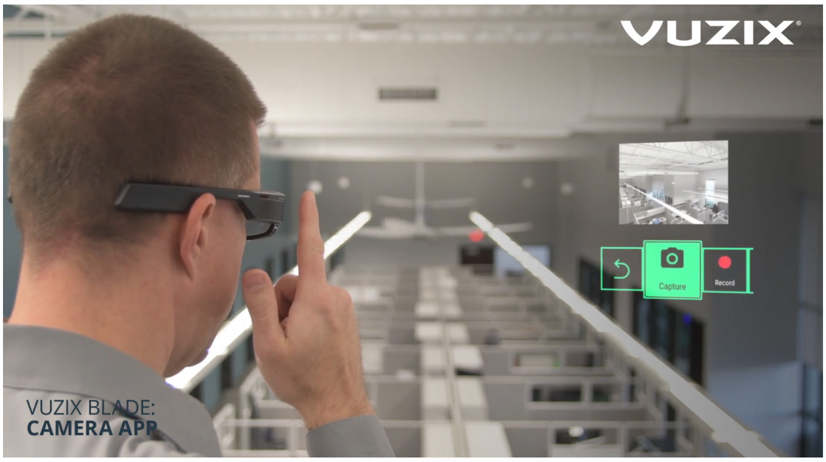


Figure 27 - *Demonstration of video recording with Vuzix Blade glasses*

MOVERIO BT-300

This autonomous mixed and augmented reality device does not require connection to an external computing unit.

The display of the glasses is capable of showing images in HD resolution (1280 × 720 px) with a refresh rate of 30 Hz. The field of view is 23 degrees.

The glasses also feature a built-in camera, microphone, compass, gyroscope, accelerometer and light sensor. The device supports wifi and Bluetooth connectivity. The camera has a resolution of 5 megapixels. Photos and videos can be taken from the perspective of the wearer in HD quality. The device also has a microUSB connector.

The device is powered by a quad-core Intel Atom x5 processor running at a frequency of 1.44 GHz. The device's operating memory is 2 GB. The storage space is 16 GB, but can be expanded by an additional 32 GB using microSDHC. The battery life claimed by the manufacturer is 6 hours. The weight of the glasses is 69 grams.

The product uses the Moverio open source operating system. The manufacturer currently also offers a range of applications for the glasses.

Compared to competing products, the glasses have high transparency. The digitally projected image is thus realistically incorporated into the real world.

Due to its nature, the device cannot be used with prescription glasses.

The manufacturer is collaborating with the Chinese company DJI, which is currently one of the key manufacturers of commercial drones for aerial imaging (photo/video). The glasses are therefore designed to enable a first person view when using camera-equipped drones. The manufacturer offers a version of the glasses under the product name Moverio BT-300 FPV. It differs from the base product by its pre-installed software for DJI drones, replaceable shade units and a controller mount that can be attached to the drone control device.

Price: USD 699 (approx. CZK 15,500).

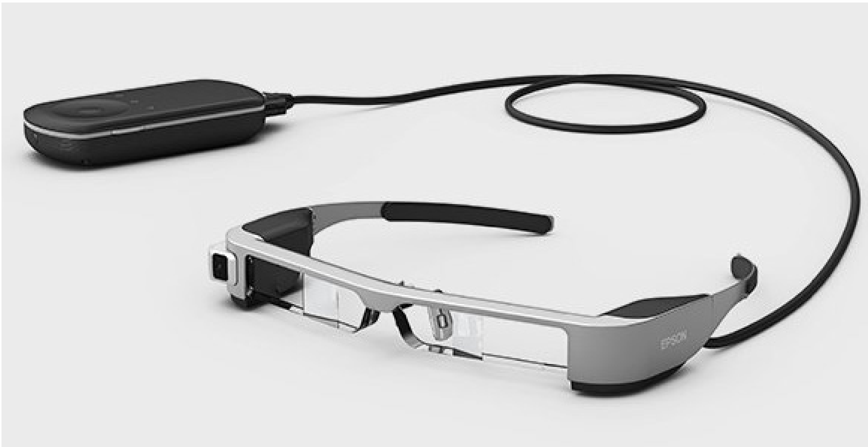


Figure 28 - *Moverio BT-300 glasses*

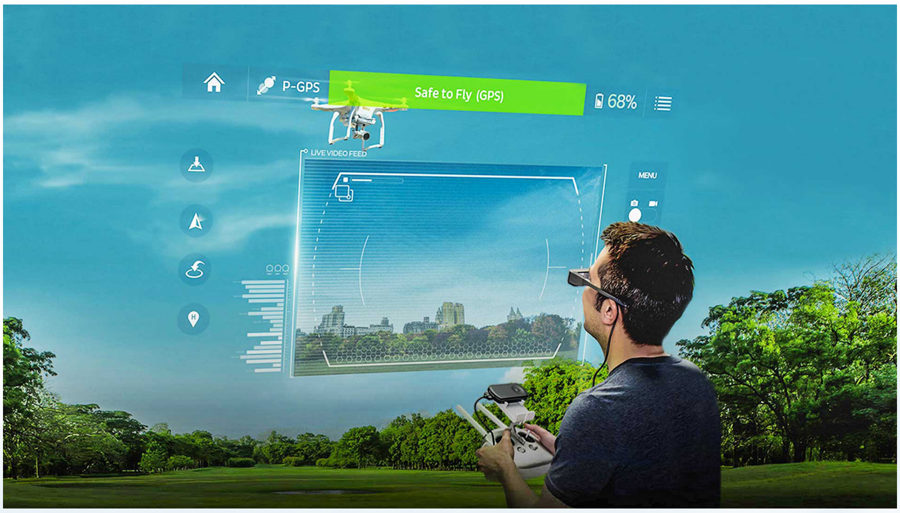


Figure 29 - *Visualization of the view through Moverio BT-300 glasses*

GOOGLE GLASS ENTERPRISE 2

This autonomous augmented reality device does not require connection to an external computing unit.

The display of the glasses projects images with a resolution of 640 × 360 px (for the right eye only). The glasses are controlled by a side touchpad built into the temples of the glasses.

The device is equipped with an 8 megapixel front-facing camera capable of capturing HD videos and photos. In addition to the camera, the glasses support wifi and Bluetooth connectivity and are equipped with an accelerometer, gyroscope, barometer, compass and GPS sensor. The device also has a built-in microphone and sound (in addition, headphones or other external audio devices can be connected via USB or Bluetooth).

The glasses run on the Android Oreo operating system. The device is powered by a quad-core Snapdragon XR1 processor running at a frequency of 1.7 GHz. The device's operating memory is 3 GB. The internal storage is 32 GB. The battery has a capacity of 820 mAh (up to 8 hours of use) and supports fast charging. The weight of the device is 46 grams.

The glasses support prescription lenses and have a foldable design (similar to regular glasses).

The manufacturer claims that the glasses are water and dust resistant.

Price: USD 999 (approx. CZK 22,500).

Figure 30 - *Google Glass Enterprise 2*

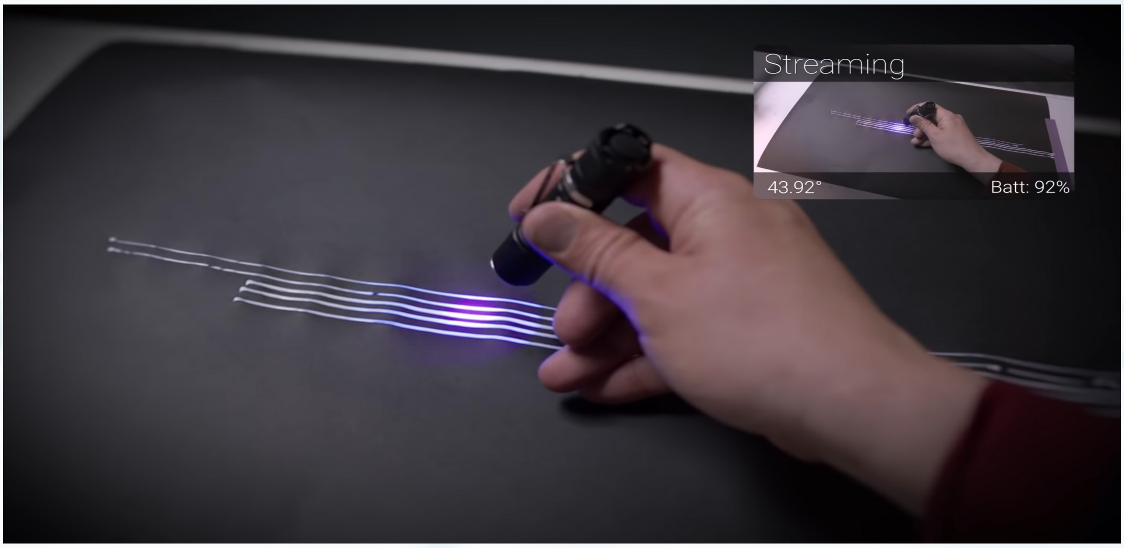


Figure 31 - *Example view (right hand corner) – streaming of first person view to another person is shown in the figure*

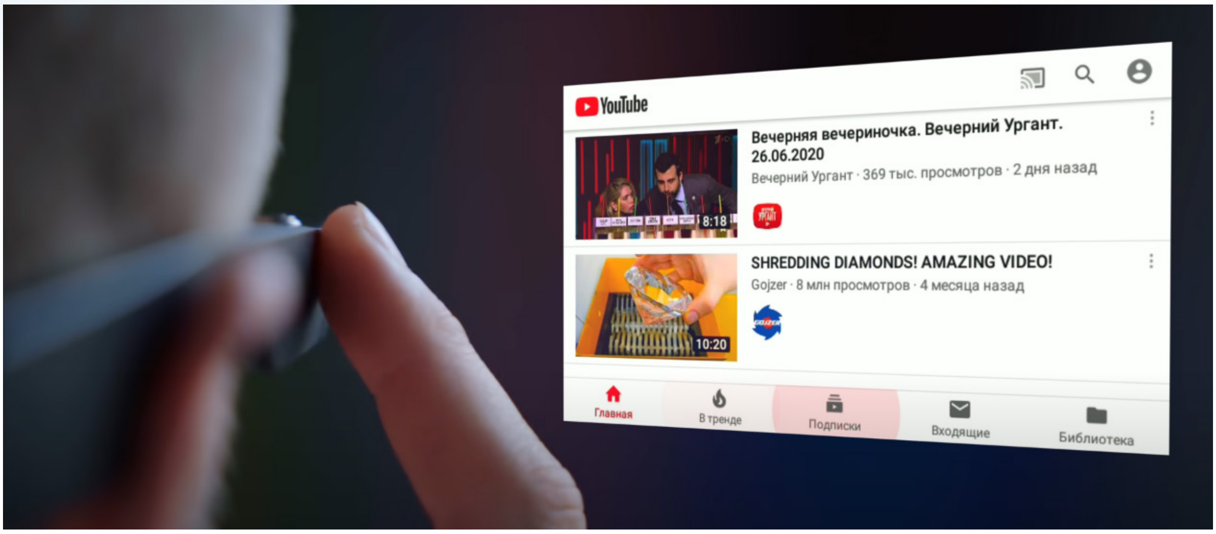


Figure 32 – *Example view – viewing multimedia content*

TOSHIBA DYNAEDGE AR100

This augmented reality device requires connection to an external computing unit (dynaEdge DE-100). The device thus consists of glasses and a minicomputer.

The projected image is displayed at a resolution of 640 × 360 pixels.

The device has a 5 megapixel camera that can record videos in up to FullHD resolution at 30 fps. It also includes built-in sound and two microphones. The device includes an accelerometer, gyroscope, light sensor, compass and proximity sensor.

The glasses use the Windows 10 Pro OS. They are controlled by a touchpad and 3 buttons. The minicomputer also allows control by additional buttons.

The computing power for the device is provided by a minicomputer powered by an Intel processor (multiple options are available – Intel Pentium 4406Y, Intel Core m5-6757 and Intel Core m7-6Y75) and an Intel HD Graphics 515 graphics chip. The minicomputer's operating memory is 16 GB. The storage capacity is up to 512 GB (SSD storage). The storage can be further expanded using a microSD card. The device also supports wifi and Bluetooth connectivity. The manufacturer does not provide further specifications for the batteries. The weight of the device is 47 grams (glasses) and 310 grams (minicomputer).

Price: USD 1,899 (approx. CZK 42,000).

Figure 33 - *Toshiba dynaEdge AR100*

Figure 34 - *Toshiba dynaEdge DE-100 minicomputer*

SOLOS SMART GLASS

Not much technical information is available about this device (e.g. projected image resolution, storage size, sensors, etc.).

This device is supposed to be compatible with Android and iOS operating systems. It can be controlled via a mobile application or by voice.

The device features a high contrast display and is therefore usable even in strong daylight. The resolution of the display is unknown.

The device supports Bluetooth and ANT+ connectivity. It also has a built-in microphone. The life of the device's lithium ion battery is approximately 5 hours per charge. The device can be charged via a microUSB cable. The weight of the device is 65 grams.

The device is mainly intended for cyclists. It allows information about the ride (distance, time, elevation, speed, calories, etc.) to be recorded.

Price: USD 499 (approx. CZK 11,000).

Figure 35 - *Solos Smart Glass*

Figure 36 - *Visualization of the view via Solos Smart Glass*

EMACULA

This is another augmented and mixed reality technology currently under development by Innovega. The purpose of this technology is to eliminate the need to have a display as part of an MR/AR device, e.g. on the temple of glasses.

In order to use this device, the user has to wear both eMacula contact lenses and glasses at the same time. Contact lenses are expected to be dispensed on prescription from an ophthalmologist. It is not clear what the planned lifetime of the lenses is (whether they are daily, monthly or other lenses).

The manufacturer claims that the device will have a field of view between 50 and 100 degrees and that the eMacula lenses will also be available in a prescription version.

Price: Not specified yet.

Figure 37 - *eMacula lenses and glasses*

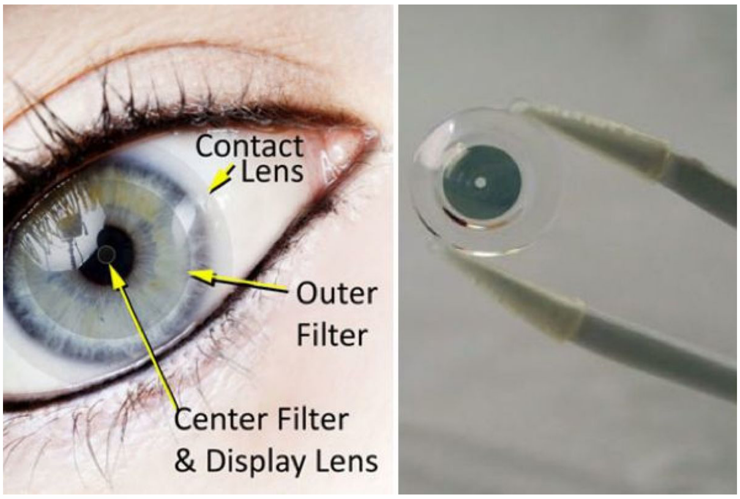


Figure 38 - *eMacula lenses with description of parts*

MR HEADSETS

MAGIC LEAP

With its Magic Leap One set, Magic Leap offers a comprehensive mixed reality solution priced at approximately USD 2,995. This autonomous mixed reality device does not require connection to an external computing unit. The device uses the Lumin operating system (a specially developed operating system based on open source Android and Linux). The software can recognize objects in space and locate walls, thus allowing realistic interaction between virtual and real-world environments. The device is powered by a six-core processor (three cores are for the operating system and the other three for running applications) running at a frequency of 1.7 GHz and 8 GB of RAM (performance equivalent to a standard laptop). The resolution for each eye is 1.3 megapixels (equivalent to 1280 × 1024 px). The field of view is 50 degrees and the refresh rate is 120 Hz. The device features a built-in microphone and sound. It also includes head, eye and hand motion sensors. The weight of the device is 316 grams. The glasses support the 6DoF standard (6 degrees of freedom of movement). The device has a storage capacity of 128 GB. The battery life per one charge is around 3.5 hours.

The device is supplied with a controller that allows the user to perceive what is happening in the virtual environment (using haptic technology – i.e. through vibrations, small movements, ultrasound action – to elicit, for example, the sensation of touching the environment). The glasses can be used without the controller (many actions can be done through gestures).

Despite its relatively compact size, the device can be used while wearing special prescription glasses (they can be ordered through the manufacturer – priced at USD 250, approx. CZK 5,500). However, there are limitations to the use of prescription glasses: SPH (dioptre) –7.5 to +3.0 and CYL (cylinder) -4 to 0.

Figure 39 - *Magic Leap One with a controller*

Figure 40 - *Visualization showing the use of Magic Leap One glasses with controllers to display a holograph*

MICROSOFT HOLOLENS 2

HHoloLens 2 is Microsoft's second generation of mixed reality glasses. The product was first launched in 2019. This autonomous device does not require connection to an external computing unit.

The device is equipped with transparent holographic lenses. The holographic display has a resolution of 2K (2048 × 1080 px) and offers a field of view of 52 degrees. The device is also equipped with multiple sensors (head tracking, eye tracking, hand movement, gyroscope, magnetometer, accelerometer, etc.). The device has a built-in microphone and sound and supports wifi and Bluetooth.

The glasses support the 6DoF standard (6 degrees of freedom of movement) and, for example, allow the user to manipulate a hologram using hand gestures (e.g. to reposition the hologram or perform other interactions depending on the software being used).

The device's internal storage is 64 GB. According to the manufacturer's specifications the glasses are equipped with a battery with a capacity allowing for 2–3 hours of active use. The device supports fast charging via USB-C and weighs 566 grams.

The device comes with pre-installed Microsoft software (Windows Holographic OS, 3D Viewer, Calendar, Cortana, File Explorer, Email, Microsoft Edge, OneDrive, Photos and more). Additional software can be purchased from official Microsoft partners (see https://www.microsoft.com/cs-cz/hololens/apps) and it can be expected that the range of products will become more and more diverse as Microsoft stated it would support an open source philosophy (free access to software source code).

The device can be also used with standard prescription glasses.

Price: USD 3,500 (approx. CZK 80,000).

Figure 34 - *HoloLens 2 glasses*

Figure 35 - *User with HoloLens 2 glasses*

Figure 36 - *Visualization of a hologram using HoloLens 2*

Other companies collaborate with Microsoft to develop different software solutions. Taqtile offers HOLOMAPS™, a virtual mapping software solution.

Figure 37 - *Holomaps*

The application displays a circular cartographic cut-out of the map with a 3D view. The user can then choose to overlay the map with additional data layers such traffic density, cartographic data or weather information. If the software was linked to the data about the positions of FPU, utility networks, etc., HOLOMAPS would find a wide range of applications in IRS unit interventions.

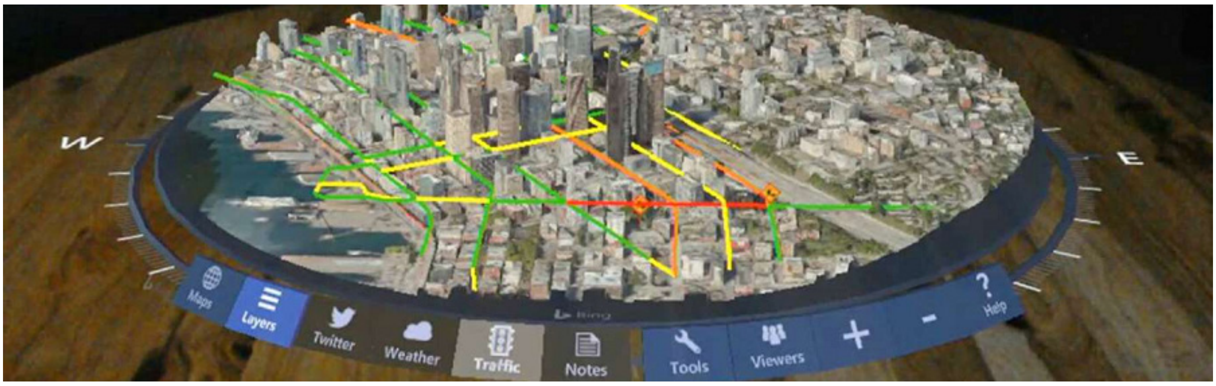


Figure 38 – *Holomaps*

THIRDEYE X2 MIXED REALITY GLASSES

This autonomous mixed reality device does not require connection to an external computing unit.

The glasses have a built-in thermal camera (low resolution only), but support connection to other thermal sensors with higher sensitivity via USB-C. With its high-luminance image, the device is suitable for both indoor and outdoor use.

The device uses Android 8.1, which increases the potential for development of new applications (an open source platform). The device has an HD display (1280 × 720 px). The field of view is 42 degrees (according to the manufacturer, this is the equivalent of a 90 inch screen at a distance of 3 metres).

The device is also equipped with multiple sensors (including environment detection, a gyroscope, accelerometer and ports for connecting other sensors). The device has a built-in microphone and sound (supports connecting headphones). The glasses support GPS, wifi and Bluetooth technologies.

The glasses support the 6DoF standard (6 degrees of freedom of movement). The device's internal storage is 64 GB. The glasses are equipped with a 1750 mAh battery. The glasses weigh only about 280 grams.

The device can be also used with standard prescription glasses.

ThirdEye currently has approximately 500 partners working on the development of MR/AR software – the applications are available through the ThirdEye Store (this store app comes pre-installed in the glasses). The manufacturer also offers customized applications developed according to the client's requirements.

Price: USD 2,000 (approx. CZK 45,000).

Figure 41 - *ThirdEye X2 MR Glasses*

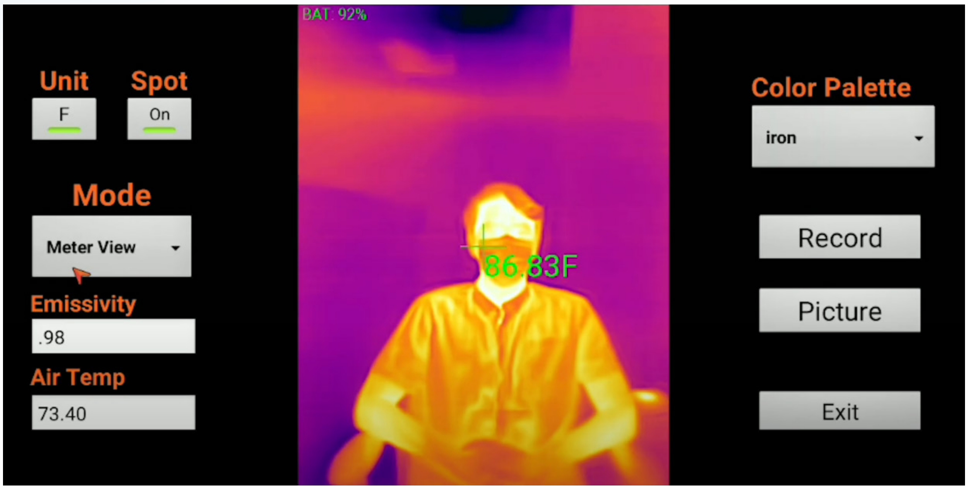


Figure 42 - *Demonstration of an image from the integrated thermal camera (temperature shown in degrees Fahrenheit)*

EVERYSIGHT RAPTOR

This autonomous mixed reality device does not require connection to an external computing unit.

The manufacturer does not specify the resolution at which the display projects the image.

The device features a 13 megapixel camera with a 75 degree field of view that can record videos in up to FullHD resolution at 30 fps. It also includes built-in sound and two microphones. The device contains an accelerometer, gyroscope, light sensor, magnetometer, barometer and proximity sensor.

The glasses run on the Android Lollipop OS. The device is powered by a quad-core Snapdragon 410E processor running at a frequency of 1.2 GHz. The device's operating memory is 2 GB. The size of the internal storage is 32 GB. The battery provides for up to 8 hours of use. The weight of the device is 98 grams.

According to the manufacturer, the device is water and dust resistant.

With the purchase of a special attachment, prescription glasses can be fitted to the device.

Currently, this product is mainly intended for professional athletes – especially for cyclists and runners. It allows the user to view information about the environment and user (e.g. route, distance, speed, heart rate, etc.) and capture logs.

Price: basic version EUR 729 / extended version EUR 819 – this version includes more storage and an external controller (CZK 19,500 / CZK 21,500) + the option of purchasing additional accessories (lighter/darker glass, adapter for inserting prescription glasses, external controller).

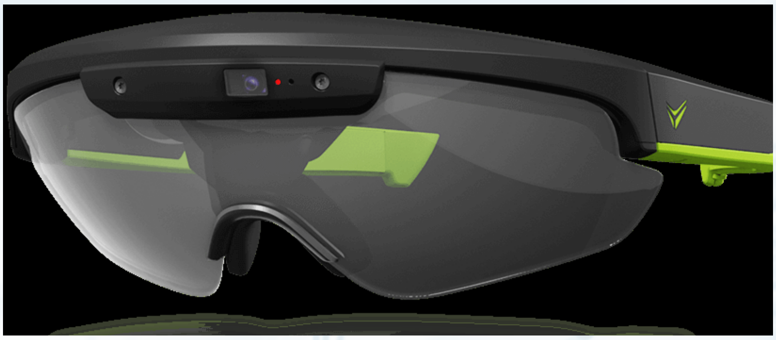


Figure 43 - *Everysight Raptor*

Figure 44 - *Everysight Raptor – view example*

● INTERACTION DEVICES

In addition to display devices, interaction devices are also important for implementation of VR technology. To enable users to navigate in a virtual reality environment and interact with virtual objects, further devices are used to sense the user's movements, controller grip intensity and gestures. These devices allow users to interact with the virtual environment using their bodies and interaction sensors. An overview of key types of interaction devices is shown in Table 4.

Table 4: *VR interaction devices*

DEVICE TYPE	DEVICE
Treadmill	VIRTUIX OMNI ONE
Treadmill	KAT WALK
Treadmill	VIRTUALIZER ELITE 2
VR shoes	CYBERSHOES
Data gloves	TESLASUIT
Data gloves	MANUS PRIME II HAPTIC + MANUS POLYGON
Volumetric capture	IO INDUSTRIES – VOLUMETRIC CAPTURE
Motion sensors	KATVR KAT LOCO
Capture	GOPRO MAX
Capture	INSTA 360 ONE X2
Capture	INSTA 360 ONE R TWIN EDITION

VIRTUIX OMNI ONE

In development. Virtuix Omni One is a VR device converting locomotion into VR (including running, walking backwards and sideways, jumping, crouching, kneeling, etc.). It does not require an external computer (only a display device is required – e.g. a VR headset). The diameter of the base is 120 cm.

Further details are not yet available (the device was announced on 7 October, 2020, with expected launch in mid-2021).

Price: in pre-sale for USD 1,995 including the display device (approx. CZK 40,000), or USD 995 for the "Dev Kit" version, i.e. without the display device – intended for VR software developers (approx. CZK 20,000).

Figure 45 - *Omni One*

Figure 46 - *Omni One*

KAT WALK

This is a VR device converting locomotion into VR (including running, jumping, sitting and crouching). It is designed for people between 150 cm and 190 cm tall and weighing less than 100 kg. The device is 280 cm high and weighs 214 kg. The design ensures greater user safety with every movement. A special pad also absorbs shock and protects the knees when the user kneels. It is fully compatible with key VR headsets (HTC, Oculus and others).

Price: Mini version starting at CZK 100,000.

Figure 47 - *KAT WALK*

Figure 48 - *KAT WALK*

VIRTUALIZER ELITE 2

Virtualizer Elite 2 is a VR trainer that can convert movement into virtual reality. It allows walking in all directions, even backwards, and running. To accurately transfer motion to virtual reality, the device is equipped with 6 motion sensors that record the direction and speed of motion at a frequency of 1,000 Hz. It also has a rotation sensor, which detects the user's rotation, and a height sensor, which allows the height of the virtual avatar to be adjusted to the real height of the user. In addition, the device uses special overshoes that allow easy movement and its precise transfer to the computing device.

Price: Unknown.

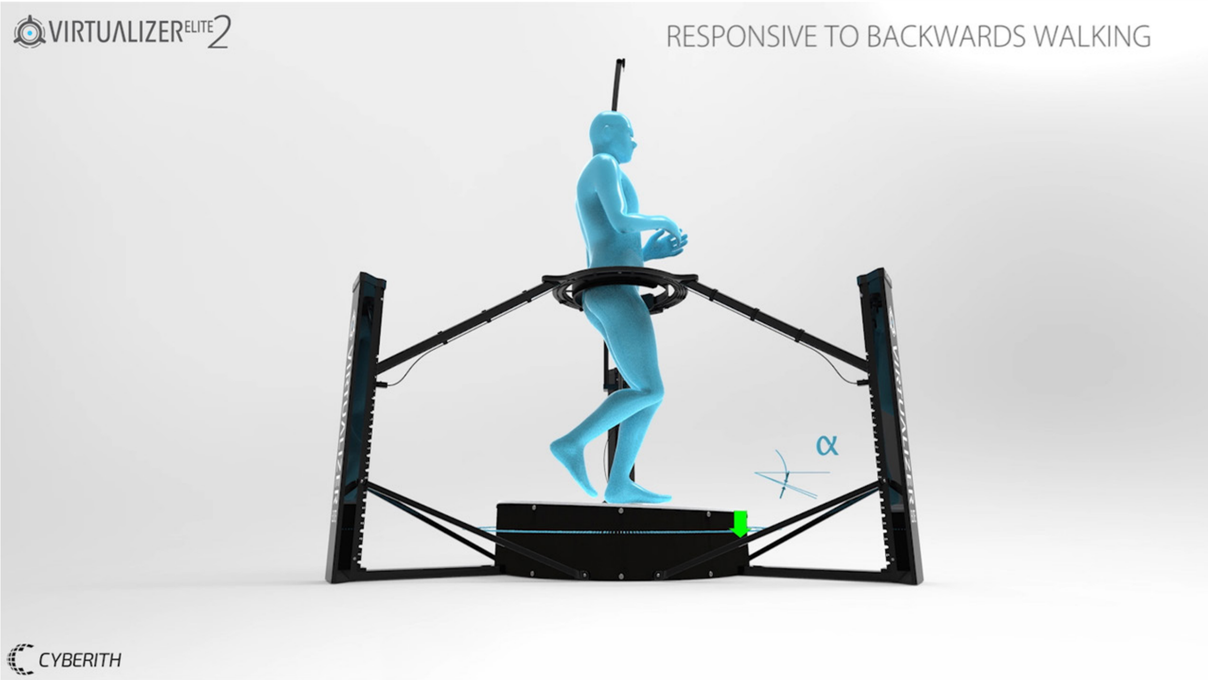


Figure 49 - *VIRTULIZER ELITE 2*

CYBERSHOES

These are shoes that can be used as a controller for VR applications. They allow the user to transfer their locomotion to a virtual environment. Cybershoes support walking, running and jumping over obstacles. In addition to Cybershoes, the company also offers Cybercarpet and Cyberchair. Both Cybershoes and Cybercarpet are required for proper functioning of this solution. Cyberchair can be replaced by another chair (but the chair should be able to rotate freely).

Currently, Cybershoes are primarily aimed at video game players (collaboration with the SteamVR platform), but they offer potential for future use in other areas as well. The device is compatible with most current display devices (Oculus Rift, Oculus Quest, HTC Vive, HTC Vive Focus, Microsoft MR devices, etc.).

Price: starting at EUR 269 for Cybershoes + Cybercarpet (approx. CZK 7,000); in the case of the Cybershoes + Cybercarpet + Cyberchair set, the price starts at EUR 449 (approx. CZK 12,000).

Figure 50 - *Cybershoes*

Figure 51 - *Cybershoes + Cyberchair a Cybercarpet*

TESLASUIT

Teslasuit has introduced special gloves that allow the user to feel the virtual environment with the sense of touch. These gloves can detect the user's hand motions and give him/her feedback according to what is going on in the virtual world. There is a special system on each finger to simulate touch and textures.

The user will feel completely different sensations when s/he touches a metal pole or when s/he runs a hand over cotton bedsheets. Along with imitating materials, the gloves are designed to mimic various temperature differences. They also have resistance and vibration systems that will make the whole experience even more powerful.

Teslasuit has been developing a special virtual reality suit over the past three years. Its haptic feedback technology should translate virtual reality experiences to the real world.

Price: Not specified yet.

Figure 52 - *Teslasuit*

Figure 53 - *Teslasuit concept*

MANUS PRIME II HAPTIC

Manus Prime II Haptic are special haptic feedback gloves. They enable users to physically perceive objects that they grasp in the virtual environment (including e.g. the surface structure of objects, etc.). The gloves are compatible with e.g. SteamVR, VIVE, Valve Index and OptiTrack technologies. They are supported for software based on the Unity and Unreal Engine 3D game engines. The gloves can be used with MANUS Polygon.

Price: Starting at EUR 1,499 (CZK 40,000).

Figure 54 - *MANUS Prime II Haptics*

MANUS POLYGON

MANUS Polygon is the newest real-time software enabling seamless motion of the entire body in any virtual environment. The solution uses inversed kinematics to dynamically reproduce the body's natural motions through 6 data points. The system generates an accurately proportioned virtual human skeleton and seamlessly re-targets and synchronizes the user's motions with the bones of a chosen avatar. This system detects the subtlest nuances in the human body's movements, producing truly realistic virtual characters without the need to combine motion capture. Polygon can be combined with MANUS Prime II Haptic gloves.

Price: USD 3,000 (approx. CZK 67,000).

Figure 55 – *MANUS Polygon*

IO INDUSTRIEC - VOLUMETRIC CAPTURE

IO Industries Inc. develops state-of-the-art speciality video cameras designed with the needs of VR/AR/XR content generators in mind. Whether it's a pair of cameras in a 3D stereoscopic rig, a handful of cameras for a 360-degree VR configuration or an array of more than 100+ cameras set up for volumetric video capture, IO Industries cameras have the features and flexibility it takes to make these configurations happen.

With volumetric capture, many precisely-synchronized cameras surround a person and capture a performance from many angles. The recorded video is processed through reconstruction software, which results in a 3D avatar of the person – a solid, moving model which can be viewed freely from all angles.

Video recordings in 360-degree format can be purchased and used to analyze the intervention.

Price: Unknown.

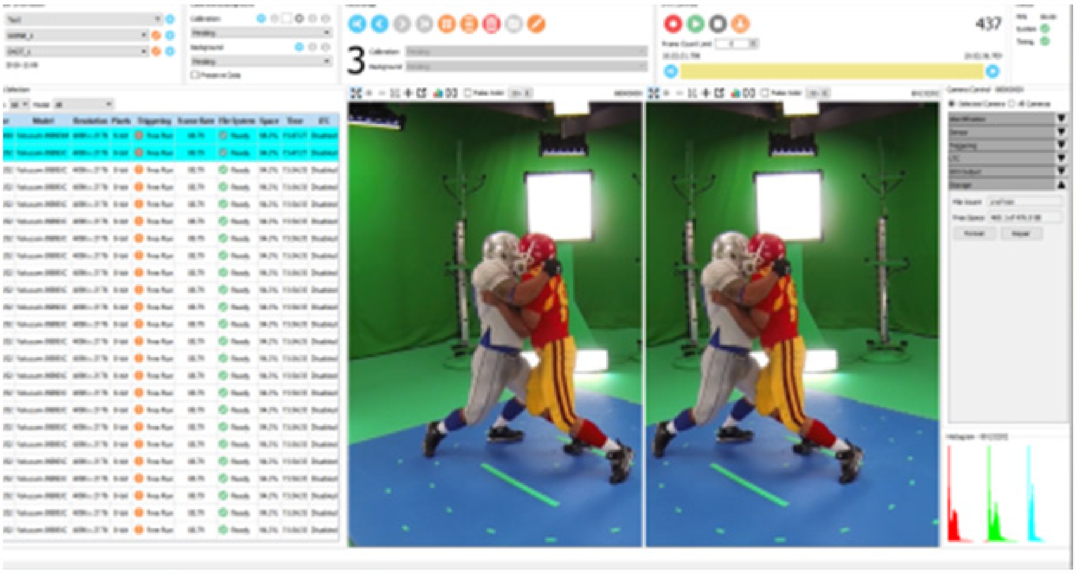


Figure 56 - *VOLUMETRIC Capture*

KATVR KAT LOCO

This product encompasses motion sensors to capture the lower half of the body – two are placed on the legs and one on the waist. These sensors enable running, jumping and other leg movements to be transferred to virtual reality. The sensors are compatible with many VR headsets (Oculus, HTC Vice, PSVR and others). The 370 mAh capacity battery has a declared battery life of 10 hours of use. The device contains Bluetooth technology with a 5 m range. The dimensions are 50×50×24 mm and the weight is 35 grams.

Price: Starting at CZK 4,000.

Figure 57 - *KATVR KAT Loco*

Figure 58 - *User with KATVR KAT Loco sensor (shown in blue)*

GOPRO MAX

The GoPro camera can capture images in spherical 360-degree resolution which provides users with VR headsets a virtual experience using the Max HyperSmooth feature, which is capable of stabilizing images very well. The camera resolution is 16.6 megapixels. The battery has a capacity of 1,600 mAh and lasts for about 1 hour of active recording. Sound recordings are recorded in 360-degree Audio format using several microphones, i.e. spatial audio recording. The device supports microSD, microSDHC and microSDXC cards and contains wifi and Bluetooth technologies. It is controlled through a touch screen. The weight is 154 grams.

Price: CZK 12,000.

Figure 59 - *GoPro MAX*

INSTA360 ONE X2

This is an outdoor camera with two lenses (front and back). The camera can capture images at an angle of 360 degrees with 5.7K resolution. The manufacturer claims that it is water resistant (up to a depth of 10 m even without the waterproof case). The device contains FlowState advanced stabilization technology, which is capable of recording during active motion without making the image blurry. The device uses artificial intelligence e.g. for underwater recording (to correct underwater colours without the need for external filters) and focusing on and tracking a moving subject after his/her name is called (the manufacturer states that it can discern and track animals, people and other moving subjects). The device supports microSD, microSDHC and microSDXC cards up to 1 TB and contains wifi and Bluetooth technologies. The device is controlled through a touch screen and voice control. The battery capacity is 1,630 mAh. The device weighs 149 grams.

Price: CZK 13,500.

Figure 60 - *Insta360 One X2*

INSTA360 ONE R TWIN EDITION

This is a modular waterproof camera that enables users to capture images in 360-degree format with 4K resolution and a frequency of 60 fps. The camera has a rotating display, the option of connecting an external microphone, voice control, automatic video editing, subject tracking and excellent stabilization. Its design enables it to be taken apart, which makes it compact and adjustable to the user's needs.

Price: CZK 14,000.

Figure 61 - *Insta360 One R*

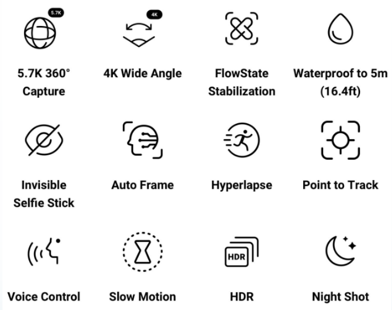


Figure 62 - *Overview of Insta360 One R features*

4.2.2 SOFTWARE

Different types of VR/AR/MR application software work on easily accessible operating systems – Windows, MacOS, Android and Linux. Virtual reality environments and virtual 3D objects are created using 3D modelling software, which enable creation of static or animated scenes but typically do not enable the user to interact with objects in the virtual environment.

According to Kuželovský, software tools that contain engines are used to create interactive virtual environments. They are capable of putting static virtual objects into motion and give them physical characteristics or adding sound to them. To create a final VR product, a VR application must be supplied with mechanics, logic and game rules (e.g. rules for collisions between virtual objects and console motion or displaying the device in the environment). Scripts, which are continuous series of commands to automate tasks, are used for this purpose. Scripts are written in various programming languages.

3D modelling software used to create static and moving 3D objects can also be used in the development of AR and MR software solutions. The rules for placement of these objects and interaction with them in the display device, if applicable, are created by specialized AR and MR development software.

The entire application programming process is supported by the framework, which provides an application framework that contains supporting programs, system libraries and/or recommended application development procedures.

SOFTWARE FOR CREATION OF 3D OBJECTS AND VR ENVIRONMENTS

VR scenes and virtual 3D objects can be created in two ways.

One is based on collecting and reconstructing real data from a real-world environment (point clouds). These data are obtained either using photogrammetry (creation of a 3D model by stitching together photos of an environment with 70–80% overlap) or through remote measurement of distances using calculations of the pulse propagation time of the laser beam reflected from the scanned object (using a LiDAR instrument) of the created 3D model or landscape. This type of reconstructed real-world environment or object can then be modified using 3D modelling software.

The second method of creating a VR environment and virtual objects relies solely on 3D modelling tools without a realistic point cloud obtained through photogrammetry or laser capture. The most commonly used tools for editing 3D objects are:

- **Maya**
- **Houdini**
- **Modo**
- **Lightwave 3D**
- **ZBrush**
- **Blender**
- **AutoDesk 3DS max**
- **SketchUp**
- **Cinema 4D**
- **AutoCAD**
- **Daz Studio.**

The most commonly used software for creation of 3D models and landscapes based on acquisition of real data (point clouds) include:

- **DronDeploy (creation of 3D models using data from unmanned aerial vehicle cameras)**
- **Meshroom – Alice Vision**
- **Regard3D**
- **RealityCapture**
- **Agisoft Metashape**
- **3DF Zephyr Pro**

- **insight3dng**
- **Pix4Dmapper (creation of 3D models using data from unmanned aerial vehicle cameras)**
- **openMVG**
- **Neitra 3D Pro**
- **WebODM (creation of 3D models using data from unmanned aerial vehicle cameras)**
- **PhotoModeler.**

SOFTWARE FOR CREATION OF VR ENGINES AND SCRIPTS

Scripts for VR solution features are typically written in C#, C++, Java, JavaScript or Python programming languages or in a language specific to the given program. The most commonly used open source and commercial software that are usually a mix of a framework engine and virtual development environment, include:

- **Unity**

  Unity is a multi-platform tool for effective development of 3D interactive applications, which includes Unity engine, a tool for game content administration and a 3D game development environment editor, in which the entire game scene is developed. This combination of an engine, application and development environment makes Unity an invaluable tool for development of games and applications for various platforms.

- **Amazon Lumberyard**

  Lumberyard is accessible with a completely public source code. It includes a graphics and script editor.

- **Unreal Engine 4**

  Unreal Engine was primarily developed for first-person shooter games. It has been successfully used in a number of other genres, including business applications and film experiences, all the way to high-quality game genres for PCs, consoles, mobile phones, VR and AR. Unreal Engine has a high degree of transferability because it is written in C++.

- **CryEngine**

  CryEngine is a game engine developed by Crytek, a German development firm. It supports the DirectX 12 interface, virtual reality development (HTC Vive, Oculus Rift, Playstation VR and open source virtual reality) and scripting in C#. It is offered on a "Pay what you want" model, which allows developers to pay whatever they feel is appropriate for the engine.

- **Godot**

  Godot is a community-developed 2D and 3D multi-platform open source game engine that is released under the MIT licence as an open source tool and is publicly accessible. The development environment runs on OS Windows, macOS and Linux (both 32 and 64 bit).

- **Game Maker**

  Game Maker is a game development application under the Microsoft Windows and other OS X platforms. In the version for Windows, the program creates EXE files directly and contains its own programming language, GML (Game Maker Language), but it is mainly a graphic interface based on an object-oriented and drag-and-drop system, which allows the user to sort everything side by side on the screen intuitively. It supports many graphic formats, and sounds and music can be imported in WAV, MP3 and Ogg Vorbis formats. The registered version also contains 3D graphics features.

- **Oculus Medium**

  Oculus Medium works with virtual reality headsets and 6DoF motion controllers. It is used to create and paint digital objects and works only on Oculus Rift.

SOFTWARE PRO AR A MR

The most commonly used development tools for expanded and mixed reality, into which users can insert 3D models they create, include the following development software:

- **Vuforia**

  Vuforia is an augmented reality software development kit (SDK) for mobile devices that enables the creation of augmented reality applications. It uses technology to recognize and track planar images and 3D objects in real time. Vuforia offers a number of AR development products, including Vuforia Engine, Studio, Chalk, Ground Plane (for adding content to horizontal surfaces), Visual Camera (expands supported visual sources in addition to mobile phones and tablets) and VuMarks (customized position markers that can be used to recognize Vuforia faces and also code data).

- **Wikitude SDK**

  The Wikitude SDK kit includes image recognition and tracking, rendering of 3D models and location-based video overlays in augmented reality. In 2017 Wikitude launched its SLAM technology (Simultaneous Localization and Mapping) which enables object recognition and tracking as well as immediate tracking without position markers.

- **ARKit**

  ARKit is an AR software development application developed by Apple for iOS devices. The software relies on camera sensor data and data from gyroscopes and accelerometers to detect and analyze users' surroundings for AR visualization. ARKit also supports fast motion tracking, face tracking, Quick Look (displaying models and scenes that can be moved and scaled easily), and various rendering effects.

- **ARCore**

  ARCore is a software development kit developed by Google that enables augmented reality application development (particularly for OS Android platforms). ARCore uses three key technologies to integrate virtual content into the real world, namely the 6DoF system, which enables phones to understand and track their positions relative to the real world; a system of understanding the surrounding environment that enables phones to detect the size and location of straight and horizontal surfaces such as the earth or a table; calculation of light conditions enables phones to estimate the current light conditions of an environment.

- **ARToolKit**

  ARToolKit in an open source and freely usable software development kit that is accessible for AR development for devices on various platforms. Aside from Android and iOS, ARToolKit can also be used for AR application in Windows, Linux and OS X. The newest version contains features such as tracking of planar images and simple black squares, generation of natural element markers, support of imaging speed in real time and easy camera calibration. ARToolKit also offers several optional plug-ins for development using Unity and OpenSceneGraph.

5. IDENTIFICATION OF OPTIONS FOR INTRODUCTION OF VR/AR/MR TECHNOLOGICAL SOLUTIONS BY FRS CR

Use of VR/AR/MR technologies to improve the work of safety system units, safety services or population protection agencies is not a new concept globally and there have been several papers and practical examples published about this topic. These users may use these technologies just as any other organization can, e.g. to streamline internal and administrative processes or manage human and material resources. However, these users' mission predetermines that they will also use these technologies for rather specific applications while respecting the conditions of the existing legal framework. The concrete areas of FRS CR's work in prevention, preparation for and response to emergencies and crisis situations present a large and extensive opportunity for application of these technologies across the areas in which FRS works – from fire prevention, informing the public about threats and risks, planned activities and training of fire protection units.

In comparison to traditional training, there are several advantages to using VR/AR/MR technologies, the foremost of which is decreasing costs and risks. Other advantages include greater control of training procedures (e.g. the order of events and the level of difficulty), support of experiential learning and option of repeating simulations as many times as participants want, which promotes self-learning and acquisition of practice *(Mossel et al., 2017)*. In some cases, use of VR technologies enables particular aspects to be studied and collected, such as data on participant behaviour and psychological data in emergency situations that are not possible or feasible in reality *(Kinateder M et al., 2014)*.

Firefighter training options based on use of VR/AR/MR technologies have a number of advantages that can be summarized as follows *(Engelbrecht et al., 2019)*:

- First firefighters have to learn how to deal with critical situations in which their lives may be at risk, and technologies provide a safe training environment in which emergency situations can be simulated without placing firefighters in actual danger.
- Technologies enable firefighters to experience various sPricerios and emergency procedures and the same application can be used to train various categories of personnel.
- Training may be provided remotely as well, which helps lower costs and the total duration of training and can even support cooperation which is beneficial for this type of activity.

Another advantage is that training using VR/AR/MR technologies enables repetition (firefighters can repeat training at their own pace) *(Rojas-Drummond and Mercer, 2003)*. Finally, training can be recorded and subsequently checked and analyzed with firefighters to understand what mistakes they made and where they could have used different solutions. Debriefing sessions thus increase transfer of knowledge and skills from the virtual world to the real world and support active learning *(Garris et al., 2002)*.

Technologies can also use dynamic and physical systems to reconstruct fire and smoke behaviour *(Cha et al., 2012)*, which is an essential element in this context, especially when firefighter training focuses on emergency procedures in buildings or tunnels. Attempts to increase the sensory spectrum of these simulations have been conducted using implementation of odour and heat radiation generators to increase the sensation of immersion into a fiery environment *(Lee et al., 2010)*.

These advantages are generally valuable to firefighters and emergency service personnel and they also give them the chance to practise repeatedly until they master the skills and abilities needed for their work and, once they have acquired these skills, to maintain/improve them.

VR/AR/MR technologies also enable creation of infinitely large and complex environments that enable training through sPricerios that are difficult or extremely resource-intensive to conduct in real life. In part for this reason, their use in training in the past has focused on emergency response *(Hsu et al., 2013)*.

In contrast to other emergency services, firefighters face a greater number of diverse dangers *(Dunn, 2015)*, namely forest fires, chemical spills, search and rescue during natural disasters, such as earthquakes, floods or putting out fires in confined urban spaces. The types of environments and threats thus differ vastly. VR/AR/MR technologies, therefore, have the potential to enable safe, absorbing and cost-effective training methods for high-risk emergencies in diverse and complex environments.

In regard to the importance of the decision-making aspect in crisis management, the VR environment has also been used to analyze relationships between firefighters and decision-making processes *(Bayouth et al., 2013)*.

In regard to firefighters' needs, use of VR/AR/MR technologies is thus an appropriate tool for preparation of firefighters (both physical and psychological) for real emergencies.

Despite the many advantages there are also weaknesses that affect existing systems in this specific context *(Engelbrecht et al., 2019)*:

- One of the relevant problems is that despite numerous efforts, there is not any device in reality that can enable natural movement in large VR environments similar to those typically found in firefighter training sPricerios.
- Another weakness is that technologies still need to improve their implementation of the feeling of being present, which, after all, is one of the main factors that help transfer learned skills from the virtual environment to real life.
- Last but not least, the usability of the system and overall user experience should also be maximized.

An assessment of key characteristics of VR/AR/MR in relation to their usability by FRS CR is provided in Table 5.

Table 5: *Key characteristics of VR/AR/MR solutions from the perspective of their usability by FRS CR*

STRENGTHS	WEAKNESSES
Cost-efficiency – logistics, organization and implementation of actions – in use of VR technologies (e.g. travel costs, accommodation, etc.)	Lack of special and training systems Cost of HR for software engineering that aims to design (e.g. of a 3D model), create and maintain programs for specific actions for which VR technologies should be directly used
Complex and diverse training sPricerios and the possibility of simulating sPricerios that are expensive/unfeasible in real training Greater control of training procedures (e.g. the order of events and level of difficulty), support of experiential learning and the option of repeating simulations as many times as participants want promote self-learning and acquisition of practice.	Insufficiently developed technologies (there are still many limitations: frame frequency, tracking, field of view, refresh rate, latency and resolution)..
Environmental conditions (higher visual immersion stimulates responses) Option to simulate external influences to achieve better immersion. It is possible, for example, to induce thermal discomfort (e.g. with a heated vest or suit) or weather conditions (ventilation fans), etc., to increase the VR training experience in general and internalization of the experience.	Technological barriers (there may be resistance to implementation of new technologies among seasoned firefighters)
Increased safety for high-risk training and repeatability	
Engagement of participants (repetition to achieve the required results). Positive psychological impacts on participants (e.g. greater self-confidence in dealing with situations), The "entertaining" nature of the training stimulates participants to engage more and supports independent learning. Potential for development of teamwork.	
Recording and assessment of data, e.g. to measure response time and accuracy of actions, and evaluate decision-making skills and problem-solving skills under stress	
OPPORTUNITIES	**THREATS**
Advances in systems engineering (the body of work about e.g. spread of fire in industrial facilities) *(Dedov et al., 2017)*, simulation of spread of fire with consideration of factors such as wind and flying cinders, and use of firefighting devices and extinguishing agents *(Moreno et al. 2014)*, emergency evacuation training system *(Ren et al., 2008)* or modelling and simulation of evacuation behaviour for subway stations *(Pelechano and Malkawi, 2008)* and high-rise buildings *(Ronchi and Nilsson, 2013)*.	Ambiguous degree of skill transfer to real situations.
Transfer of findings from other areas (use of VR for fine motor training can be directly transferred e.g. to training with mobile fire extinguishers. The same may be assumed for harsher motor skill training, e.g. handling large equipment such as firefighting hoses, ladders or vehicles)	Repeated exposure to hazardous events in the VR environment may lead to formation of habits and loss of caution in real-world situations. The VR environment may cause kinetosis or even nausea – abdominal pain, dizziness ("VR sickness").
Increase of mental and physical resilience. VR training using external influences e.g. inducing heat discomfort (suit/vest) can improve the user's physical condition and decrease stress arising from unfamiliar events.	
Cost-efficiency / VR environment devices are more affordable owing to growth in graphics systems performance and commercialization.	

The following section describes all of the FRS CR agendas in which VR/AR/MR can be practically applied. This section is divided into the following user groups:

- FRS CR members and members/employees of fire protection units[3];
- Population[4];
- Professional crisis management public (particularly self-governments and critical infrastructure entities).

5.1 MEMBERS OF FRS CR AND MEMBERS OF FIRE PROTECTION UNITS

Technologies can potentially be broadly applied in almost all areas of theoretical and practical training. They enable demonstration of selected theoretical knowledge in interactive and appealing formats, where in contrast to real-world situations the training participants are not placed in any danger.

Use of the investigated technologies by FRS CR can be basically divided into virtualized professional preparation tasks and intervention or direct performance of services. Professional preparation of FRS CR members using VR, AR or MR may be connected to the existing training system[5] and can expand or innovate this system.

The various types of virtualization may be used in FRS CR courses and may also become part of regular professional preparation at stations or specialized FRS CR worksites or FPUs. Specific technologies may be integrated into the following training activities for FRS CR members:

1. Introductory courses
    a. Basic professional preparation (BPP) for members not included in Fire Protection Units (hereinafter "FPUs")
    b. Onboarding training for new firefighters for members included in FPUs
2. Professional qualification courses (repeated in 5-year cycles)
3. Specialized courses
4. Other courses per other legal regulations (e.g. OHS, driver training)
5. Regular professional preparation
6. Training of IRS or crisis management units

As part of professional preparation, short training modules narrowly focused on specific types or branches of tasks as well as complex model situations including linkages between all tasks and the correct remembering of procedures in different types of interventions or activities can be designed. In regard to the costs and time required, it is not realistic to digitalize all activities. It is definitely appropriate to virtualize activities that, in the case of an intervention or performance of activities, evoke a higher degree of stress or may be dangerous, or situations that have complicated conditions to address

3 For members or employees of FPU II or lower categories, resultant virtualized activities are used in regard to their category and purpose. In the area of population protection and crisis management, similarly to FPU, the resultant products may be used for members of voluntary organizations collaborating with FRS CR in its work (e.g. the Czech Red Cross).

4 For preparation of the population for emergencies and crisis situations.

5 In general, professional preparation of FPUs based in particular on the FPU Firefighting Guide, FPU Training Guide and other internal guides (e.g. chemical service), or curriculum of professional qualifications courses, may be transferred to some of the described realities, particularly VR and AR.

or do not occur frequently, and the virtual environment will therefore ensure quality preparedness of firefighters.

For the needs of interventions, training or use in real-world conditions, the most appropriate of the investigated realities is MR. In contrast to complete substitution of the real world with a virtual environment, MR/AR devices interact with the real-world environment and merely insert virtual elements into it. For example, a firefighter on duty can obtain a great deal of premium information about the environment in which s/he is by using MR/AR devices, without significant impact on his/her perception of the real world. When deploying MR (or AR, if it is useful) in the real-world conditions of an intervention or other type of duty, it is necessary to ensure that specific units cooperate with one another, i.e. particularly firefighters and response commanders (for FPU interventions), or specific members of management committees, Regional Operations and Information Centre operators, etc.

Specific solutions will need to be modified according to the number of professional preparation participants, i.e. focusing either on training individuals or cooperation within a given squad or other part of the unit. The specific virtualization variations must also encompass alternatives with different meteorological conditions and times of day – in other words modification of external conditions.

5.1.1 FP UNITS

Specific tasks are described from the position of a firefighter, meaning a member of a fire protection unit, who is expected to complete an onboarding course and other specialized course if applicable (mechanical service, underwater work, working at heights and above free depths, chemical service, etc.). During firefighter training, particularly during onboarding courses or other specialized courses, we can certainly recommend using a virtual polygon to familiarize participants with the given environment or possible situations and only then moving on to a real polygon (e.g. flashover container or breathing apparatus training). This procedure will better prepare firefighters for interventions and decrease training stress and can lower the probability of injury during training.

In order to use virtual technologies during interventions, firefighters must have the commensurate basic equipment. To ensure firefighter safety, "smart" response suits equipped with a device monitoring basic vital signs should be standard issue. For movement in the field, or remote guidance of firefighters by the response commander, an integrated display device in the firefighter's helmet with a camera that enables switching to thermal imaging or recording for firefighters and possibly a tablet or other device for the response commander will be essential. A drone will provide a comprehensive overview of the situation or monitoring in particularly hazardous environments. Ideally, each drone will be equipped with a thermal camera and other sensors that improve monitoring of the situation (e.g. hazardous chemical substance detection).

A) CROSS-CUTTING ACTIVITIES

PROFESSIONAL TRAINING

Virtual reality can be used to create a simulator of firefighting development training with sPricerios of various events. The simulator should be capable of responding to specific decisions made by firefighters. It should also be able to create simulations for the entire squad. This simulator should serve as the most basic tool during training and be included to an appropriate degree in the curriculum of onboarding courses for new firefighters. The intention is that firefighters learn the basic firefighting intervention knowledge such as the specific tasks of a given number in the squad, cooperation and communication during interventions and familiarization with and operation of basic technical equipment.

Similarly, many drone manufacturers offer flight simulators which, however, are significantly limited by the 2D display and do not prepare users as fully for the real-world environment. There are now flight simulators with augmented reality available, which make it possible to fly a virtual drone in a real-world environment. The only requirements are augmented reality glasses and a controller from the drone manufacturer. As soon as these two tools are connected, virtual drone control training can take place anywhere. There are applications available for this purpose with modes in which you can e.g. collect things with the drone or avoid obstacles.

INTERVENTION

Mixed reality facilitates better orientation in the field, particularly during limited visibility (night, smoke, underground areas). It enables navigation in the field when the destination of the trip is entered (e.g. during search interventions in the field), and is also capable of modelling the terrain of the surrounding environment and thus preventing injury to firefighters, particularly during night duty.

Use of MR/AR technologies makes it possible to consider navigation of firefighters to a specific location in a building (or outside of a building). A simple map would be displayed in part of his/her field of view that would show his/her current location, the target destination and the route to get there (similarly to GPS navigation).

With the use of digitized building floor plans, firefighters could also be warned of any hazards in the given space (e.g. areas where flammable or hazardous materials are regularly stored could be marked with coloured symbols, etc.).

B) TECHNICAL AND MECHANICAL SERVICES

PROFESSIONAL TRAINING

Virtual training with technology and equipment, particularly with special equipment, can serve as a basic introduction to the technology and equipment in onboarding courses, as well as a way to deepen knowledge in follow-up courses or regular professional training. Through learning sPricerios, participants first learn how to control the equipment step by step and then modification of increasingly complex sPricerios may take place. Knowledge acquired in virtual reality will subsequently be applied in training and in real-world environment. This will reduce the risk of personal injury and damage to special equipment that could be caused by mishandling.

A VR simulator focusing on the use of FP equipment, particularly water tenders (various types of traffic situations, transport to the intervention scene based on real fire district maps, pump operation), fire truck ladders/platforms (setting, movement within a built-up area, use of a firefighting basket and rescue of persons) and cranes (modelling of rigging techniques, load lifting and transport). Visualization of individual technologies with the possibility to operate them is used to get familiar with driving and technical parameters of vehicles in order to automatize their use.

INTERVENTION

At the same time, the technology can be used to navigate drivers to the intervention scene (or to any destination: it can be just a regular journey unrelated to any emergency event). However, such a design would be required that does not compromise the driver's concentration on the road ahead. These technologies are now mainly available as AR mobile applications to be used on mobile phones, tablets or on-board computers, provided that they are equipped with a camera. However, it is conceivable that similar applications could also be implemented through smart glasses. Theoretically, a display device could be integrated into or projected onto a windscreen. The display could show route directions and the estimated time of arrival; road boundaries could be highlighted when driving at night, etc.

During an intervention, it would be useful to use AR to display technical specifications of the equipment and technology to ensure their correct and safe use, e.g. information about safe load limits for fire truck ladders/platforms or a sectional ladder.

With the assistance of AR/MR, technology deployed on site can be set up in a way that does not obstruct movement while being kept out of the danger zone; this can be done using a catalogue of vehicles owned by particular regional FRS units, comprising the vehicles' parameters, and using projections of the site vicinity on the map.

C) CHEMICAL SERVICE

PROFESSIONAL TRAINING

A virtual polygon can be used to learn about various types and characteristics of hazardous substances including decontamination methods. It is possible to experience their effects on the body and their reactions with different types of fire extinguishing agents, as well as other substances.

INTERVENTION

Virtualization of a hazardous substance release to the environment. Identifying and displaying information about the substance on the firefighter's display device. At the same time, MR can be used to improve decontamination methods, where decontaminated areas could be highlighted in colour in the firefighter's display device.

D) WORKING ON AND UNDER THE WATER

PROFESSIONAL TRAINING

VR can be used by a diving team especially in model situations to train for dives with a focus on critical underwater situations. Modelling of water flows and known problematic diving spots, which divers encounter most often, can be used to improve underwater orientation. Especially for cave diving, it would be useful to learn about water-filled cave formations in the Czech Republic in the virtual environment first – to train orientation and to strengthen the knowledge base in the field of cave diving.

INTERVENTION

Given the nature of diving activities of FRS CR, which comprise mainly lifesaving, the most beneficial solution would be to display parameters monitored during a dive on the diver's mask, namely the amount of air left in the scuba tank, the dive time and achieved depth. If possible, given the external conditions (working underwater), it would also be useful to monitor blood nitrogen levels. Displaying the data in the firefighter's field of view would significantly contribute to his/her safety during this risky activity.

E) WORKING AT HEIGHTS AND ABOVE FREE DEPTHS

PROFESSIONAL TRAINING

VR can be used by climbing teams to practise climbing techniques on a virtual polygon. Similarly to diving teams, known rock formations can be modelled with critical areas marked in order to improve firefighter safety.

INTERVENTION

During the intervention, it would be possible to display technical parameters of ropes and model their loading when rescuing persons from rock formations and cable cars. At the same time, it is possible to assist helicopter landings by projecting and measuring dimensions of a suitable landing area.

F) TRAFFIC ACCIDENTS

PROFESSIONAL TRAINING

This type of equipment can be used for a specific type of vehicle when training extrication skills for traffic accidents. There could be different VR sPricerios involving different types of vehicles, alternative propulsion vehicles, ADR vehicles, trains and civil aircraft. At the same time, the sPricerios would involve modifications related to a specific damage to vehicles with entrapped passengers. It is also possible to incorporate cooperation with other IRS forces into the sPricerios. The added value of such training would be participant safety, the possibility to train even in adverse weather conditions and the use of equipment that might not be physically available for training purposes at the given moment. This polygon could use all three reality forms:

- Polygon for proper training of intervention tactics in model situations (VR);
- Virtual polygon with realistic means (AR);
- Virtual vehicle and crew that will respond to signals and procedures at the intervention site (MR).

INTERVENTION

In the event of a traffic accident requiring extrication of passengers, the technology can identify the type of vehicle and indicate the structural elements of the body (of a train or aircraft) where extrication equipment can be used with the highest efficiency. At the same time, vital signs of the vehicle crew can be monitored in order to protect their health functions and prevent their deterioration.

During traffic accidents, the technology is able to recognize vehicles with an alternative power source (CNG, hybrid, e-vehicle) and display where a power source unit is located in a particular vehicle. The technology has a built-in camera to monitor the temperature of the power unit in the event of a fire hazard, during the fire and during subsequent extinguishing operation for this type of vehicle.

G) FIRES

PROFESSIONAL TRAINING

VR can be used to simulate reactions of fires of different classes to particular extinguishing agents, to observe fire development in different environments (apartment, family house attic, motor vehicle, forest vegetation, etc.) and in different external conditions (no wind, light wind, rain, etc.) to practise the use of appropriate extinguishing procedures with a focus on the extinguishing culture and the FP technology (fire attack, working with a nozzle, deployment of transport and attack lines, etc.). In addition to the effects of different extinguishing agents, it would be possible to demonstrate smoke movement within a room during the fire (neutral plane, chimney effect, smoke spreading in unprotected corridors) and the search for persons in difficult conditions (poor visibility, high-rise buildings, underground spaces, educational and recreational facilities, etc.). At the same time, virtualization can also be used to simulate real intervention conditions by virtualizing dangerous phenomena, e.g. flashover, backdraft and rollover, to improve skills that are needed for their identification.

A great benefit is the possibility of training even during adverse weather conditions, because the training can take place in classrooms. At the same time, the environment is not polluted by foam, powder or combustion gas emissions. Firefighters are currently trained in a firefighting training tower. This existing simulator can be fully digitized and used with both VR and AR/MR.

INTERVENTION

Some of the currently developed MR/AR technologies are designed to improve firefighter orientation in poor visibility environments (e.g. smoky rooms or poorly lit areas). These technologies are based on the principle of detecting contours and highlighting them in colour in the display device. Firefighters are thus able to find their way even in environments where the human eye does not suffice. These solutions will provide for improved safety of responding firefighters while allowing for more efficient execution of the intervention, which can ultimately help save lives and assets. Some of the technologies under development also make it possible to highlight people who are alive. This feature can facilitate the rescue or give the firefighter a better idea where his/her colleagues are positioned to avoid unintended separation from the rest of the group. In combination with a digital building plan, this tool significantly helps rescue persons from fire, but also increases firefighter safety. Digital firefighting documentation and digital building plans serve to support both the response commander and the FPU when intervening in buildings; they simplify orientation in smoky areas and help identify escape routes.

The use of thermal imaging cameras plays an essential role especially in case of fire, but also for other hazards. Firefighters may have images taken through thermal imaging cameras mounted on their helmets projected onto their display devices. It makes it easier for them e.g. to locate a fire, search for hidden fire outbreaks, find persons and animals in the rubble, etc. Some of the currently available technologies display precise temperatures. This function could be useful e.g. when intervening in areas where hazardous materials are stored or to rescue persons under low visibility. Another useful tool is the acquisition of images from a thermal imaging drone, which provides a comprehensive overview of the situation. By projecting the information onto the firefighter's display device, it significantly improves his/her orientation in a smoky environment. It also enables effective use of extinguishing agents. Clearly, in the future, drones controlled through the use of MR can replace firefighters in some cases (e.g. survey of extremely dangerous buildings, fighting fire with modern extinguishing agents, e.g. fireballs).

H) RESCUE OF PERSONS AND ANIMALS

PROFESSIONAL TRAINING

Simulation in the virtual polygon can also be used to practise rescue of persons and animals, especially when entering enclosed spaces; course participants will be familiarized with the methods of unlocking structures and picking locks, or when it is necessary to rescue animals.

INTERVENTION

When saving or rescuing animals, a display device can be used to obtain information about suitable animal capture and handling procedures.

When searching for people or animals, a thermal imaging drone can be deployed, as well as terrain modelling techniques. The already searched areas can be highlighted. All of this will be displayed on the firefighter's helmet device.

I) BUILDING DESTRUCTION

PROFESSIONAL TRAINING

Especially the USAR would find it useful to have a virtual polygon focused on rescue of persons from debris and cave-ins. This polygon would be used to learn how to manage rubble, search for persons in the rubble and how to properly secure the scene of collapse.

INTERVENTION

During the intervention, we would be able to use digital building documentation related to the intervention site to compare the rubble with the original building for easier orientation when searching for persons under the rubble, or establishing access to power lines and other hazards in the building. At the same time, MR can be used to model the effectiveness of shores installed in a collapsed building or cave-in.

A thermal imaging camera or drone can be used to search for people under the rubble.

J) FIRST AID

PROFESSIONAL TRAINING

Although we currently have relatively good first-aid training simulators outside of virtual reality (resuscitation manikins – e.g. CPR manikins), virtual reality may represent additional added value or an alternative to relatively expensive high-tech simulators (e.g. where manikins are able to respond to rescuers' actions).

Many VR technologies for first-aid training combine resuscitation manikins and virtual environment for this reason. This solution helps participants immerse in a specific situation (audiovisual perception) while offering various sPricerios.

However, it is worth noting that the identified studies[6] on the use of VR technology in healthcare focus on more "invasive" branches of healthcare (namely surgery, orthopaedics and gynaecology) rather than first aid. In spite of that, these technologies can also have considerable potential for first-aid training as evidenced by the existence of some specific VR simulators.

INTERVENTION

In the event of mass casualty incidents, the location of individual triage stations can be modelled to bet-

6 POTTLE, Jack. Virtual reality and the transformation of medical education. Future Healthcare Journal [online]. 2019, 6(3), 181-185 [quoted 2020-10-17]. ISSN 2514-6645. DOI 10.7861/fhj.2019-0036. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6798020/;
SAMADBEIK, Mahnaz et al. The Applications of Virtual Reality Technology in Medical Groups Teaching. Journal of advanced medical education & professionalism [online]. 2018, 6(3), 123–129 [quoted 2020-10-17]. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6039818/

ter organize the search, triage, treatment and transport of the injured. At the same time, the firefighter would be able to see (using MR) on his/her display device the colour coding of each person according to the START or TIK methods without the need to check the triage identification card.

The firefighter's display device could also comprise basic instructions how to administer aid while monitoring the vital signs of a person.

K) INTERVENTION SCENE HAZARDS

PROFESSIONAL TRAINING

Every firefighting activity involves certain types of hazards. The FPU Firefighting Guide identified a total of 22 types of intervention scene hazards listed in Table 6.

Table 6: *Types of hazards at the intervention scene based on the FPU Firefighting Guide*

1.	Physical exhaustion	2.	Mental exhaustion
3.	Infection	4.	Intoxication
5.	Burying and crushing	6.	Collapse of structures
7.	Ionising radiation	8.	Polychlorinated biphenyls
9.	Explosion of explosive materials and pyrotechnic mixtures	10.	Suffocation
11.	Drowning	12.	Chemical burns
13.	Electrocution	14.	Burning
15.	Overheating	16.	Scalding
17.	On roadways	18.	On railways
19.	Falling from a height	20.	Hypothermia and frostbite
21.	Loss of orientation	22.	Dangerous animals

It is important to pay maximum attention to different types of hazards and therefore they should be simulated in the virtual environment in two ways:

- As a separate simulation for each type of hazard;
- As part of all of the above activities where a particular hazard exists; these types of hazards can augment simulations with random elements to make problem-solving more difficult for participants.

5.1.2 RESPONSE COMMANDERS

This involves strategic and tactical management; particular activities are described from the viewpoint of a response commander who is expected to have completed an onboarding training for new firefighters and a course of tactical management, or a course of strategic and tactical management, as the case may be.

PROFESSIONAL TRAINING

The virtual reality simulator can help response commanders train the management and organization of an intervention site using comprehensive sPricerios. At the same time, it is possible to simulate work under pressure and the need to extensively communicate not only with the intervention site, but also with its surroundings. The simulator can offer a variety of hazards and non-standard situations occurring at the intervention scene, without risking firefighters' lives. The simulator does not have to use VR elements only; AR elements can also be used, especially in case of cooperation between the response commander and his/her squad. It would be possible for each sPricerio to respond to particular firefighters' decisions.

INTERVENTION

In addition to coordinating rescue and recovery, one of the main tasks of the response commander is to ensure firefighter safety. In this respect, MR/AR can make a major contribution. Using a combination of information about the condition and movement of a firefighter from a smart response suit, or from a sensor that the firefighter will have on him/her, and from a digital plan of the building supported by drone monitoring, the response commander will get a detailed overview of the situation at the intervention site. Owing to that, AR can then model the entire situation on a virtual map. The response commander can thus test different intervention options in the virtual environment, or remotely guide his/her team to a safe place.

Digital firefighting documentation combined with AR/MR can also increase the firefighter safety. The response commander can navigate firefighters in a building or guide them out of a life-threatening situation.

Another possible area of deploying MR/AR technologies in combination with drone services is information management. Existing MR/AR technologies make it possible to obtain, analyze and process information from the environment. The above functions can be used in the context of intervention command, subsequent analysis of the intervention, etc. Many augmented reality devices currently offer the possibility of recording or even streaming footage (live stream directly to the end user). This could be useful e.g. in cases where the footage would be streamed, e.g. to the staff of the response commander, which would support the response commander in his/her command.

5.1.3 OPERATIONS AND INFORMATION CENTRES

PROFESSIONAL TRAINING

Modelling of an emergency situation for the operations centre – operational level, training of the Regional Operations and Information Centre focused on the process of receiving information from a caller, giving directions to the intervention site, collaborating with other FRS CR organizational units or other agencies.

SERVICE PERFORMANCE

Tracking the location and monitoring of arrival times of vehicles to the intervention site on a virtual map and getting an overview of the situation in the area (uncovered sections, transport of equipment). The flow of information can be reversed, too. Intervening firefighters can receive needed information to their MR/AR devices from people outside of the intervention scene. This can include e.g. setting a target on a map to be reached by the intervening firefighters, audiovisual footage from the intervention scene, etc.

Information from a caller to an emergency line can be received with the help of artificial intelligence – through a virtual operator.

The situation can be evaluated based on data from municipal surveillance systems or people's smartphones. .

5.1.4 INTEGRATED RESCUE SYSTEM

A) PSYCHOLOGICAL SERVICE

PROFESSIONAL TRAINING

Training of procedures and psychological and social assistance in a virtual environment with the help of "living and breathing" virtual role-players who react and express emotions based on an assisted conversation or therapy.

SPricerios for coping with different sorts of life events (loss of a loved one, intervention/emergency event/crisis related trauma).

SERVICE PERFORMANCE

Virtual meeting with a person who is provided with psychological support in a comfortable environment; possibility of playing relaxation videos and using various techniques. Conversation with a psychologist who cannot be at the intervention site immediately, but at least virtually.

When working with people with vision or hearing impairment, the spoken word can be translated into sign language, or a virtual interpreter can be deployed who may also be replaced by AI.

B) CHEMICAL SERVICE

PROFESSIONAL TRAINING

Instruments and environments can be virtualized to enhance the training of operators responsible for the preparation, maintenance and review of chemical service assets and decontamination technology, for the detection and collection of hazardous chemical samples, or for the actual performance of decontamination tasks.

SERVICE PERFORMANCE

An expert can provide remote instructions, e.g. using a drone, robot, smart glasses or an application, either at the intervention site or directly in the danger zone.

C) MECHANICAL SERVICE

PROFESSIONAL TRAINING

In the sphere of mechanical services, VR can be a great instrument to test/practise maintenance/ operation of FRS CR machines and vehicles. As an added value, VR enables modelling of machines and creating of sets in the environment where the operators' training takes place. Thanks to stereoscopy, natural movement and precise controls, virtual reality opens up amazing possibilities already when creating a new model. Also, it's not a problem to scale down the work to be able to conveniently use a "virtual workbench". Similarly, it is possible to enlarge models even of the smallest of objects. Although the option of changing the scale is also available when working on a regular PC, it definitely does not provide benefits comparable to virtual reality. This is because the firefighter becomes immersed in it, which allows for completely intuitive handling of all functional elements without being limited by the screen size. It is no longer necessary to clumsily handle the entire model on a flat screen. Large machinery can be easily observed from all angles and positioned as if it is standing right in front of the firefighter. S/he can simply take one part after another and assemble everything as a kit with an unlimited number of parts. Another great advantage of VR is unlimited flexibility in changing the scale of work. This makes it possible to design a construction, extension or reconstruction of a fire station based on the mechanical service requirements and activities. As a result, innovative solutions and existing model improvements can be identified to a larger extent, which can then be applied, e.g. when accommodating user requirements related to technology procurement.

SERVICE PERFORMANCE

Working in the VR environment can speed up every step of vehicle inspection, maintenance and repair. Due to the option of cooperating directly in the VR/MR environment, technology can be remotely maintained/inspected in real time, saving operators' resources and time. Similarly, the VR/MR environment can be used to streamline the process of formulating user requirements when procuring technology.

D) IRS

SERVICE PERFORMANCE

The national coverage by FPUs provides for firefighting and rescue activities in the whole territory of the Czech Republic. It is aimed at creating such links between different FPUs that will ensure more efficient use of special firefighting equipment, FPU members' expertise and more purposeful distribution of subsidies to municipal voluntary fire brigades. The use of VR technologies to model alternative FPU coverage sPricerios (including links to other IRS units) could improve this system and increase its efficiency.

Similarly, VR/MR can be used to streamline the process of preventive selection and modelling of events that are currently listed in STČ (list of activity types). By analogy, these tools can be used for planning and training.

5.1.5 PREVENTION SECTION

A) BUILDING FIRE PREVENTION

PROFESSIONAL TRAINING

Fire prevention staff training could move from a 2D paper environment to a 3D VR/MR environment which can be used to model and control impacts of particular fire prevention requirements on assessed structures and operations. Similarly, virtualization can be used to train inspection activities while working with real buildings and various types of structures. Using VR, inspectors can walk through a facility, deal with identified deficiencies and apply correct procedures. Using VR solutions, we can accelerate the standardization of procedures and training of inspectors based on the existing typology of operations and buildings.

The introduction and adoption of the BIM method in the Czech Republic by construction designers will create space for mutual synergies, e.g. in terms of using building data generated during the BIM process for preparation of virtual sPricerios for fire prevention training, ensuring transparency and conceptual approach of FRS CR through the training of its own personnel and – last but not least – a better recognition of fire prevention requirements on the part of construction designers.

SERVICE PERFORMANCE

Digitization of design documentation for buildings and structures would open up space for virtualization of fire protection design as such. Virtual project plans and other construction documents displayed to the inspector would then simplify the process of identifying deficiencies and deviations of the actual situation from the project design. The application of these approaches would also be reflected in the virtualization of firefighting documentation. Subsequently, the data can be used for direct support of response commanders and FPUs intervening in a building, facilitating navigation in smoky areas while searching for escape routes – MR/AR. We can also imagine that a VR/MR application can be developed based on digitized plans of e.g. apartment buildings, industrial facilities, hospitals, shopping centres, to be used by their users. In the event of emergency, the users who have downloaded the application would be directed to the nearest fire extinguisher, defibrillator or evacuation route in the building, to an assembly area, etc.

B) IDENTIFYING THE CAUSES OF FIRE

PROFESSIONAL TRAINING

During fire investigator training, VR/MR can be used to create training sPricerios and reconstructions that will teach participants correct procedures to identify the causes of fires, e.g. how to protect traces and evidence. A tool for virtual modelling of the fire development would also be useful to suitably complement, among other things, real-world investigation experiments.

SERVICE PERFORMANCE

Similarly, during the investigation process as such, a fire scene can be virtualized using e.g. a 3D scanner, which can be useful to verify certain findings and help identify ultimate causes of the incident. The scanned areas could be virtually browsed at any moment and the digital technology would make it possible e.g. to reconstruct the event (e.g. to compare different possible sPricerios of the causes of fire) and to carry out a virtual investigation experiment.

5.1.6 POPULATION PROTECTION AND CRISIS MANAGEMENT SECTION

Virtual reality as a new tool for planning and dealing with emergency events and crisis situations from the viewpoint of population protection and crisis management. The key elements include a 3D model of the territory, virtual meetings and data available from other applications, which are projected into sPricerios dealing with emergency events and crisis situations.

A) POPULATION PROTECTION AND CRISIS MANAGEMENT TASKS

PROFESSIONAL TRAINING

Virtual models of industrial accidents and hazardous substance releases can be developed for training purposes. At the same time, VR can be used to train the application of population protection measures (independently, or as an extra level of virtual FPU exercises), with a focus on flood protection measures – modelling of waves and construction options, mounting and operation of emergency survival means (emergency survival containers, humanitarian emergency response facilities) and the organization of an evacuation/assistance centre, etc.

At the same time, through repeated training, users can acquire the necessary habits for performing tasks related to population protection, e.g. evacuation route modelling.

SERVICE PERFORMANCE

VR as a support of population protection mechanisms, in particular through virtualization of the mounting of a humanitarian emergency response facility in a chosen location (floor plans for particular sections of a humanitarian emergency response facility to be built over a certain area). Virtualization of an evacuation centre / relief centre / emergency survival facility / shelter – modelling people flows and centre capacity. Finding the evacuation route to the evacuation centre. Calculating and modelling the throughput of evacuation routes and routes in general (e.g. by collecting data from the operation of existing navigation applications and Google maps).

For crisis management purposes, VR/AR/MR instruments can be used to model various sPricerios of existing or future emergency events including various measures' impacts. At the same time, within the framework of a threat analysis, cascading effects and mutual synergies of particular threats can be modelled, including those that are difficult to practise (high impact/low probability).

B) COMMANDING OFFICERS (STRATEGIC MANAGEMENT LEVEL)

PROFESSIONAL TRAINING

VR can be used to model typical emergency events and crisis situations. Modelling of sPricerios (including random phenomena) capturing the sequence of commanding officers' actions in order to improve decision-making processes at the strategic level.

SERVICE PERFORMANCE

Modelling of the course of emergency events and crisis situations once particular measures are adopted (AR).

Virtual connection of commanding officers with the intervention scene, with a fire investigator, emergency committee or other agencies, using smart glasses or a holographic imaging device. Commanding officers can receive data transmitted from drones/cameras/sensors at the intervention site.

5.2. POPULATION PREPAREDNESS

When it comes to population preparedness, VR/AR technology can be used to effectively train large groups of people in proper emergency response procedures while explaining the importance of proper behavioural patterns to ensure effective self-protection and mutual support. Gamification of life situations increases knowledge and skill retention. AR technology allows for the training of specific activities with minimum extra costs (e.g. fire extinguisher functions, personal protection equipment, self-protection, escape routes, first aid, etc.). This approach aimed at instilling the correct behaviours in the public can be applied both in general (dealing with emergency events, e.g. blackout), or specifically: where relevant for, e.g., people in areas at risk of flooding, in external emergency planning zones (radiation accidents) or in areas at risk of a hazardous substance release, etc.

Similarly, VR technology can help rehearse emergency notifications, effective use of various types of emergency alerts, proper reporting of emergencies and conveyance of key points. There can be a mobile application that allows for the use of pre-set sPricerios in a room (once scanned – e.g. using LiDAR on iPhone) – the user would have to deal with a projected event (e.g. smoke in the room, Christmas tree fire, burnt food, etc.). An application designed for the public could also use this technology to navigate to points of interest (e.g. escape route from a digital building plan, nearest fire extinguisher, AED, etc.).

5.3. EDUCATION OF THE PROFESSIONAL PUBLIC – MAYORS, CRITICAL INFRASTRUCTURES (CI) ENTITIES

PROFESSIONAL TRAINING

Virtual reality can take education to a whole new level. It is a new interactive option for better memorization. Once immersed in a simulation, video or interactive application, the participant develops a feeling of presence in the environment and in the moment, far more than just through observing a particular event or environment from the outside. In the field of education of the professional public, emergency or crisis simulations can be used for individual phases of a decision-making process. These types of training would also be suitable for mayors of municipalities with extended competence, statutory town mayors, emergency committee members, CI entities, NGO members and volunteer fire departments, as well as other stakeholders dealing with specific emergency events and crisis situations in a given area. This training/virtualized exercise would be used to ensure that the participants are able to work with information, understand the context, work as a team and communicate effectively in order to translate their knowledge into skills to be applied in day-to-day activities and solutions related to emergency events and crisis situations.

For instance, a pre-programmed (AI-based) virtual assistant can be used for mayors/regional governors to facilitate their training for emergency events and crisis situations. These training sessions can also provide participants with negative experiences of what can happen if they fail to follow certain statutory procedures. This negative experience helps them realize that non-existent or poor decisions can have irreversible consequences in real life; it also simulates work under time pressure. This realistic concept, combined with virtual reality training, substantially accelerates the process of learning and acquiring necessary skills.

The use of virtual environments for conferences, sessions and meetings has become increasingly popular. Its benefits include almost 100% concentration on the topic discussed or on the meeting as such. As soon as the participants put on their VR glasses, they immerse in the VR environment.

VR elements can be used to prepare emergency plans and incident management plans; similar principles can be applied when preparing emergency preparedness plans or other documents, e.g. pursuant to the Act on the Prevention of Major Accidents. They can include namely virtualization and training of operation aspects and geography resources for emergency preparedness plans, a tool to model the functionality of emergency preparedness plans for CI entities (analysis, action plan, measures to ensure the functioning of the CI entity), modelling of interdependencies, mapping of other vulnerable entities important for the functioning of CI, engagement of security directors / liaison officers in virtual exercises, including relevant ministries.

6. IDENTIFICATION OF THE AVAILABILITY OF VR/AR/MR TECHNOLOGIES

6.1 FLAIM TRAINER

Flaim Trainer (Deakin University, 2021a) was developed by researchers at Deaken's University Institute for Intelligent Systems Research and Innovation (IISRI) in cooperation with General Dynamics Information Technology; it combines elements of virtual and augmented realities.

The current FLAIM Trainer software version includes 20 pre-programmed model sPricerios for practising firefighting techniques. The firefighter is moving inside a real room and extinguishing virtual fires. The operator can check fulfilment of the specified task using a connected screen showing the user's current field of view. The real feel of the VR environment is provided by a firefighting suit, gloves and helmet (with a breathing apparatus) equipped with TRACKER modules that immediately heat up to a high temperature (similarly to real contact with a fire). As a consequence, any object than can be seen in reality through the glasses can be transferred to the virtual world and handled. In the training simulator, the nozzle acts real and can simulate realistic jet reaction force. This is done by a mechanical reel that adjusts the force of the nozzle reaction according to the flowing amount of water (or another fire extinguishing liquid based on the setting). The breathing apparatus makes breathing more difficult exactly the way it would be in a real intervention. During the training, the system records movement and postures to allow for retrospective evaluation. A virtual fire can respond to the spraying method, so the trainer can use VR to accurately demonstrate which procedure is correct and which is not. For example, if water is sprayed on a hot frying pan with oil, it will explode, etc. In addition, the helmet can be used to make realistic sounds with real intensity thanks to the built-in headphones. The non-transparent glasses feature an AR camera, and the entire exercise can therefore be set in an authentic environment.

HW requirements: The device uses the commercially available HTC Vive system equipped with a Tracker module. Within the Flaim Trainer system, the Tracker module is mounted on the firefighting equipment components. The trainees use the following firefighting components:

- Display device (HTC VIVE VR glasses) including a VR headset and a breathing apparatus;
- Standard hose pipe system with a jet reaction force simulator, equipped with an HTC Vive Tracker;
- Standard heat suit with a vest, emulating temperature conditions in the proximity of a fire.

The system can be used for fire attack training once the user's components are connected to an external screen/TV set, the breathing set and the tracking tower.

The system can be transported in three travel cases (55 kg in total). Assembly and set-up of the training at the requested location should take 10 minutes. The operating staff undergoes a two day training course.

Price: Direct purchase costs for introduction of the FLAIM Trainer amount approx. to CZK 1.26 million. A set of the FLAIM Trainer system with a 1-year warranty service and upgrade, including a set of batteries, is offered for EUR 43,500 (approx. CZK 1.15 million). A two-day on-site training course for the operating staff including transportation of the FLAIM Trainer and travel costs is offered by the VR Support Center Europe from the Netherlands for EUR 3,500 (approx. CZK 95,000). An extra support and library update, thanks to which you can update scenarios, upgrade software and access the helpdesk, is offered by the Dutch FLAIM Trainer representative for Europe for EUR 6,500/year (approx. CZK 75,000/year).

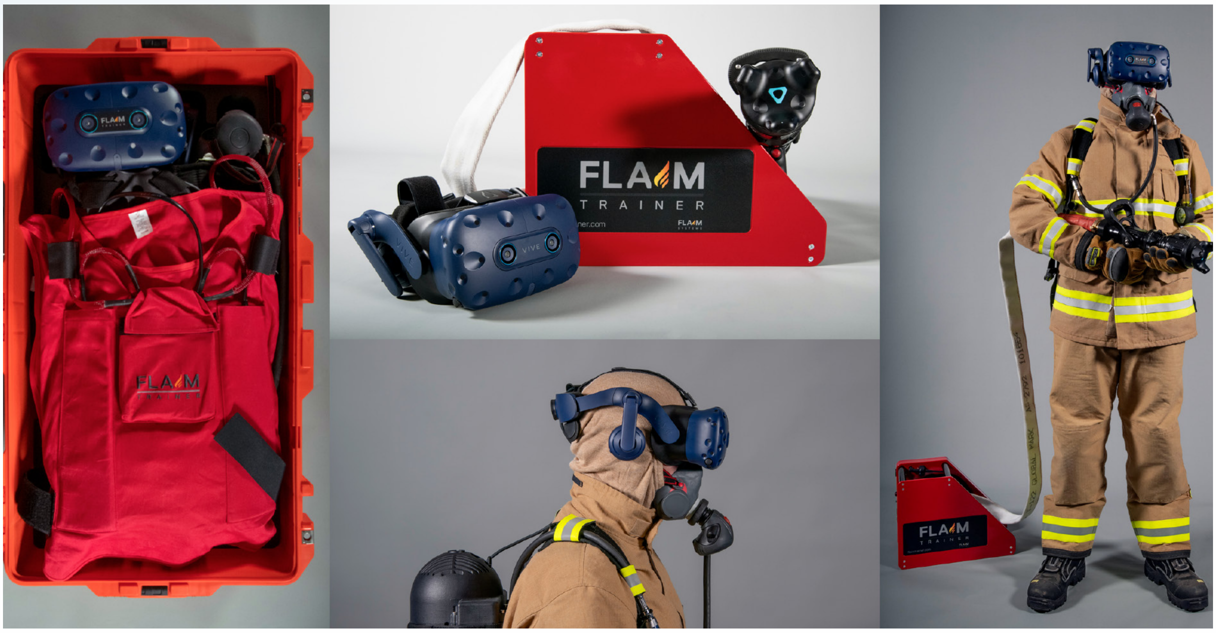


Figure 63 - *Flaim Trainer – hardware components*

6.2 FLAIM EXTINGUISHER

Systém FLAIM Extinguisher (Deakin University, 2021b) je určen pro školení k hašení začínajícího požáru, tj. pro prvotní protipožární INTERVENTION, pomocí realistických VR scénářů simulujících běžné situace (požáry v domácnostech, pracovištích, kancelářích, autech atp.) Využitelné jako součást školení BOZP pro zaměstnance. K dispozici je aktuálně 15 scénářů pro použití vhodného hasebního přístroje (různé náplně – voda, CO_2, pěna, prášek…). Simulace je vytvořena včetně realistického chování ohně, kouře, vody, pěny apod. Uživatel si při započetí scénáře zvolí vhodný hasicí přístroj (podle hasiva) pro daný scénář. Výrobce kromě standardních scénářů nabízí možnost nechat si vytvořit scénář podle požadavků klienta.

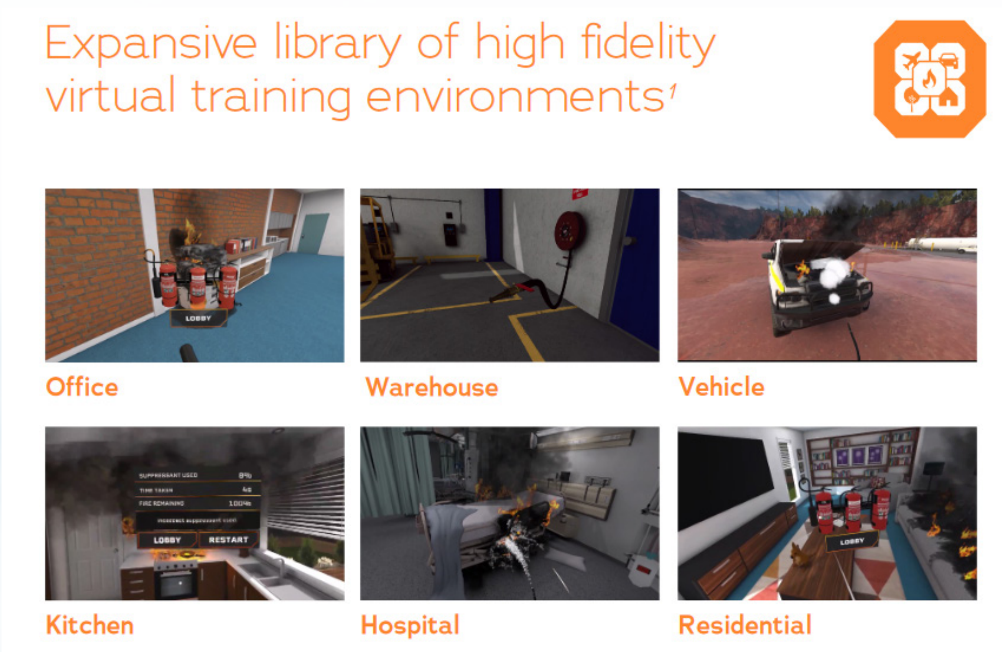


Figure 64 - *Flaim Extinguisher - software*

HW requirements: Systém používá Pico neo2 6DoF headset v kombinaci s VR senzory na hasebním přístroji (ovládací páku ventilu, míření a pohyb).

Zařízení je přenositelné v kufru (4,2 kg), zprovoznění za 5 minut. Systém by měl vydržet fungovat až 5 let (nebo zhruba 5 tisíc hodin). Možnost vývoje scénářů na základě poptávky.

Price: Pořizovací Price systému FLAIM Extinguisher Pro je €7,995 bez DPH (200 tisíc Kč) a zahrnuje sadu s jednoletý servis a update. Extra roční podpora a aktualizace knihoven stojí €900 bez DPH (zhruba 24 tisíc Kč).

6.3 LUDUS FIRE SAFETY

At present, the company Ludus (Ludus, 2020) develops a fire extinction simulator using an extinguisher. A simulator of fire of solids has only been available so far, but the company intends to incorporate other types of fires in its solution, too. The system should include a model fire extinguisher with a VR sensor and a standard VR headset. The system is expected to provide various environments for extinguishing fires; currently only a scenario of an industrial warehouse fire has been made fully available. All the remaining components (apart from the warehouse fire) are still being developed (i.e. the model fire extinguisher has not been for sale yet).

Figure 65 - *Ludus Fire Safety*

Ludus's VR solutions focus not only on fire protection but also on other activities related to occupational health and safety. These include, among other things, work at height, cardiopulmonary resuscitation, electrical hazards, etc.

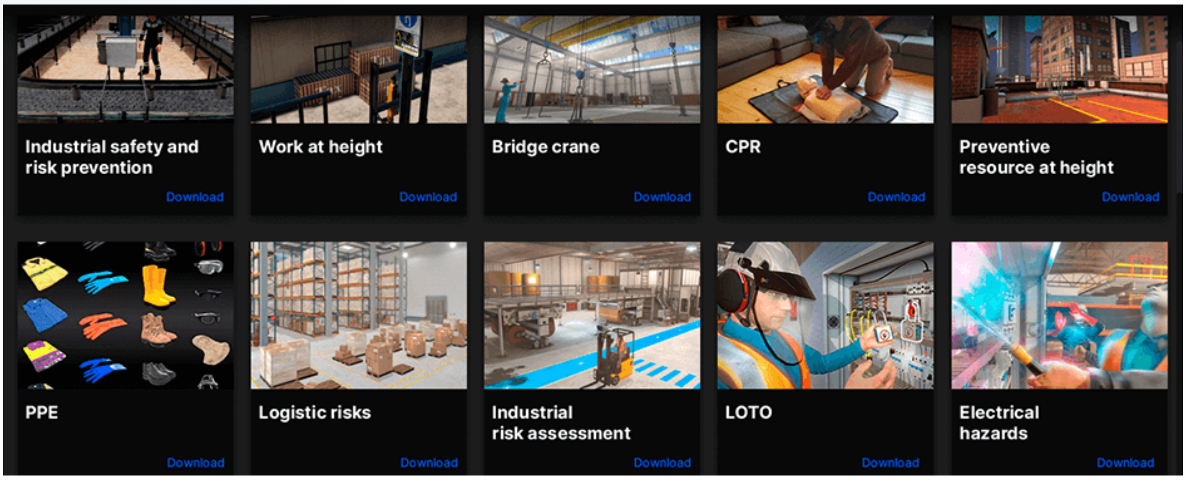


Figure 66 - – *Examples of other VR solutions by Ludus*

HW requirements: The solution is compatible with Oculus Rift and HTC Vive Cosmos headsets. It should also include a model fire extinguisher as an operating device.

Price: EUR 990/month (approx. CZK 26,000/month) for the software access (no other equipment is included in the price and its price is unknown).

6.4 RIVR INVESTIGATE/LINK

RiVR Investigate (Reality in Virtual Reality Limited, s.a.) is a software solution offering a realistic training to investigate the cause of fire in VR. The photo-realistic scenarios allow the user to investigate the scene of fire using the same tools available in the real world. The user can look everywhere, open doors and closets and pick up objects in the scene. The tool belt offers the user evidence markers, flashlight, camera, dictaphone, gas testing device and placeable large scene lighting. There is also an evidence lab. The product is offered for a single user and also includes a managed training function for supervisors and administrators (remote training is possible).

To ensure training fidelity, RiVR scenes are based on real fires (controlled burns). In preparation for every VR scenario a realistic set-up of for example a room, kitchen or office is built. Fire is then realistically set to the scene through short-circuiting electrical appliances or for example a fallen candle. The fire scene is then recorded using laser-scans and 3D mapping and the data are entered in a 3D modelling tool. This VR solution achieves a truly realistic rendering of the scene.

Figure 67 - *RiVR - software*

The RiVR Link version provides a product intended for simultaneous training of 3 to 15 users (however, up to 64 headsets can be connected on-site or using remote access) using VR scenes made of 360-degree videos and images. RiVR Link allows the tutor to use the first person view (moving in a 3D scene created based on 360-degree data) as well as a third-party view (virtual classroom with video projection).

HW requirements: A VR headset (HTC Vive), including the drivers, base stations, external computing unit and external monitor are required to use the software. RiVR Link uses a proprietary device to record data (RiVR 360 Shooting kit). Pico G2 headsets are used for the subsequent viewing of recordings.

The solution contains a tutorial to teach the user how to work with the software.

Figure 68 - *RiVR – hardware components*

Price: The VR Support Center Europe offers the RiVR software for GBP 15,000/year (CZK 435,000) per one installation; the price includes a library of RiVR System files with at least 6 post-fire scenes for investigation and another 6 scenes which will be added in a year's time. The software also allows users to record the VR investigation for future viewing, expert discussion and training.

RiVR Link with the Shooting kit costs GBP 14,000 (CZK 428,000) for a set of 15 RiVR Link headsets, and GBP 1,625 (CZK 50,000) for the Shooting kit. The price includes support during the first year of operation; subsequent support costs GBP 4,000/year (CZK 122,000/year).

6.5 ROSENBAUER ALTS + CAGE

The company Rosenbauer (Rosenbauer, 2019) used the Formula 1 simulator to create a training solution for operators of aerial ladders and elevating platforms ("aerial ladder tactical simulator", ALTS) based on the HTC platform.

Figure 69 - *Rosenbauer ALTS*

The training solution includes a database with a variety of buildings and facades. It can also be extended with the Cage operating panel. This combined solution makes it possible to train rescue of persons or entire groups from windows and balconies and to increase difficulty of conditions (weather, smoke) at any time.

Figure 70 - *Rosenbauer ALTS*

The company also prepared a special training simulator for its firefighting vehicles at airports. It consists of a driving compartment connected to a screen with a size of 8 x 4 meters. The VR software provides scenarios of various types of burning aircraft which must be extinguished from the driving compartment of the firefighting vehicle.

HW requirements: Two high-performance notebooks, VR glasses, two joysticks and a ladder control console are required for this solution. A minimum of 25m2 of free space and a plug socket are required for proper operation.

Price: Unknown. The equipment will be available for purchase or hire.

6.6 COAL SERVICES

Coal Services (Coal Services Pty Ltd, s.a.) developed its safety training simulator allowing employees to experience hazardous situations and to virtually move in dangerous locations, but in a safe and controlled VR environment. The virtual reality system is precise and realistic because it digitally simulates more than 50 km of mining tunnels, covering all regular mining methods and potential accidents. For open-cut mines, the virtual reality uses real terrain data.

The VR technology is used in three unique environments. VR Domes are ideal for use by up to three persons. The Domes capture the participant's field of view, with manoeuvring via a joystick. Parameters: 1 projector, 180-degree dome with a 3.5 m diameter. This platform is particularly suitable for individual training, such as training of use of escape routes, individual emergency management, etc. Second is the 110-degree VR Curved Screen, which accommodates up to 30 people in a lecture room. Parameters: 3 projectors, screen sized 8 × 3.5 m. This platform is mainly used for subsequent analysis of tasks and situations solved during the VR exercises. Third is a 360-degree VR Cylindrical Theatre which can accommodate 15 to 20 participants. VR is operated through a central operating console (ROCK) and a wireless tablet. The ROCK features include real-time GPS navigation, module activation and change and scenario switching at the touch of a button. The VR includes a training environment which is methodologically divided in the following levels: Easy Access to the VR Mine, Safe Exposure, Extended View, Retention and Recall and Competency Based Assessment.

Examples of the individual training modules: Emergency Preparedness and Response (Underground). The course develops competency and confidence in preparing for, and managing all aspects of an emergency situation. This is a 5-day course. The price is USD 1,830 (approx. CZK 40,000).

Coal Services also offers the following modules:

- Mines Rescue Brigadesmen Training Modules;
- Isolation Modules;
- Supervisors Modules;
- Hazard Awareness Modules;
- Self Escape Modules.

The VR training covers all aspects of mining industry requirements. The virtual mines capture the mining process from cutting of the coal face right through to surface processing. This provides the full flexibility for training modules to suit specific customer needs and to adapt to any situation. The VR images are accurate and lifelike for improved graphic and spatial immersion, and the modelled mining equipment and processes are true to reality.

HW requirements: 12 projectors (6 pairs), area of 120 m2, 6 computers generating a 360 degree 3D view, 1 computer for sub-coordination of the image generator. The platform can realistically simulate the mining environment and emergencies, including gas leakage. In this case, the individual simulated gaseous components in the environment are virtually detectable using a smartphone application. 3D glasses are used for a perfect 3D virtual view.

Price: Unknown.

6.7 DREAMPORT – SIMULATOR OF ACTIONS IN CASE OF FIRE

The purpose of the Russian simulator by DreamPort (DreamPort, s.a.) is to teach employees the correct sequence of actions in the event of a fire in an office building. A three-story office building is used as a model example. The users may choose the appropriate extinguishing method depending on the fire type (the simulator includes ignition of a flammable liquid, fire in the electronic panel, etc.). However, the system is not purely a fire extinction simulator; it is a tool familiarizing the users with the appropriate procedures and their correct sequence in the event of a fire in a building (e.g. calling help, warning other people in the building, trying to extinguish the fire after selecting the correct agent, airing the smoke, etc.).

The software offers two modes: training and exam. In the training part, a virtual guide accompanies the users and tells them in detail about the correct actions. In the exam mode, the user must perform the necessary actions independently. The actions are then evaluated and the user is given a grade based on the results.

The product has been positively reviewed by the Russian Ministry of Emergency Situations.

HW requirements: As for hardware, this simulator should be compatible with glasses based on the HTC VIVE, HTC VIVE PRO and HTC VIVE COSMOS technologies. The manufacturer provides no other details.

Price: Unknown. DreamPort offers creation of bespoke VR simulators starting from RUB 200,000 (approx. CZK 65,000); it can be assumed, however, that for more complex simulations, the price will be much higher.

Figure 71 - *DreamPort – software*

Figure 72 - *DreamPort - software*

Figure 73 - *DreamPort – software*

Figure 74 - *DreamPort - software*

6.8 DREAMPORT – WORKING AT HEIGHT SIMULATOR

The purpose of this simulator by DreamPort (DreamPort, s.a.) is to teach the users the correct procedures in high-rise working using a safety harness. The simulator has been developed for the state-owned company Russian Railways.

The software offers two modes: training and exam. In the training mode, a virtual guide accompanies the users and tells them in detail about the correct stages of safe ascent to a height. In the exam mode, the user must decide independently. If the task is completed incorrectly, the student falls down in virtual reality, which shows, among other things, that work at height should not be neglected, because any mistakes can be fatal.

HW requirements: As for hardware, this simulator should be compatible with glasses based on the HTC VIVE, HTC VIVE PRO and HTC VIVE COSMOS technologies. The manufacturer provides no other details.

Price: Unknown. DreamPort offers creation of bespoke VR simulators starting from RUB 200,000 (approx. CZK 65,000); it can be assumed, however, that for more complex simulations, the price will be much higher.

Figure 75 - *DreamPort - software*

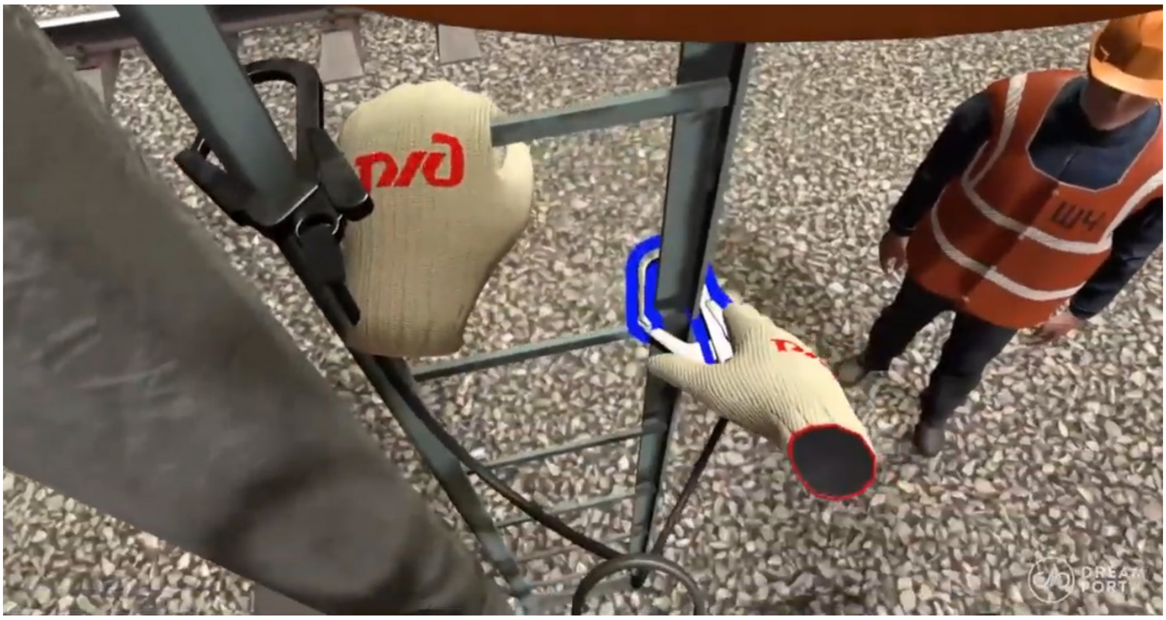


Figure 76 - *DreamPort - software*

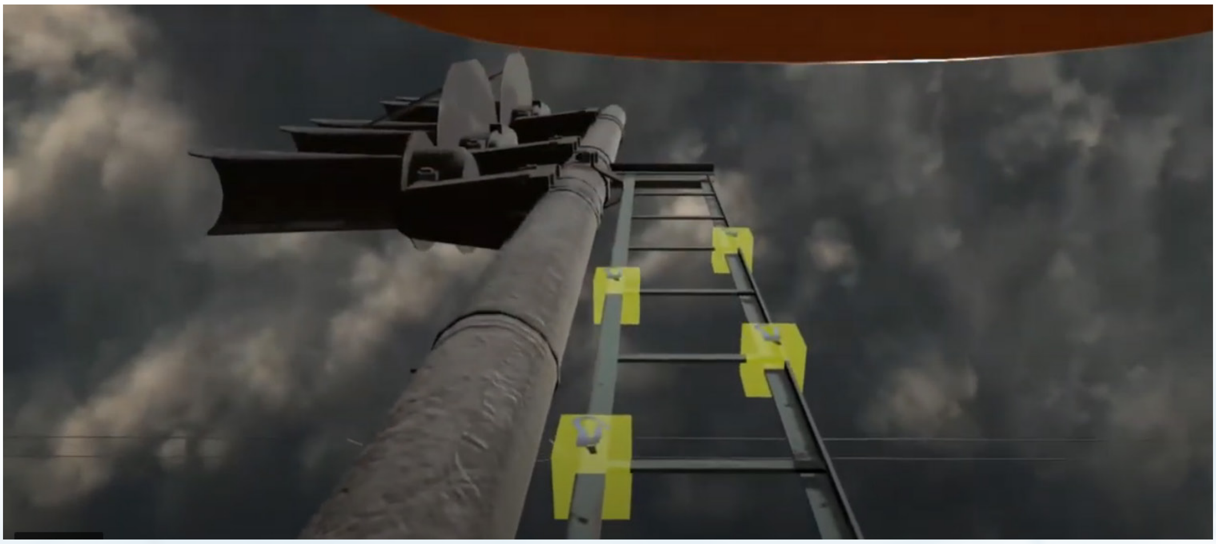


Figure 77 - *DreamPort - software*

6.9 DREAMPORT – SIMULATOR FOR ELIMINATION OF OIL, WATER OR GAS LEAKAGE

The main aim of the DreamPort (DreamPort, s.a.) project was to create a multi-player simulator for employees working in the energy sector (gas and oil industry) that would teach them using team work to resolve emergency situations such as oil or water inflow or gas leakage.

The scenario includes an uncontrolled inflow of oil or water or gas leakage due to extraction. This later leads to a fire. Once the fire is extinguished, a preventer must be replaced.

The training results and progress of each employee are recorded and saved in the user's personal account.

HW requirements: As for hardware, this simulator should be compatible with glasses based on the HTC VIVE, HTC VIVE PRO and HTC VIVE COSMOS technologies. The manufacturer provides no other details.

Price: Unknown. DreamPort offers creation of bespoke VR simulators starting from RUB 200,000 (approx. CZK 65,000); it can be assumed, however, that for more complex simulations, the price will be much higher.

Figure 78 - *DreamPort – software*

Figure 79 - *DreamPort – software*

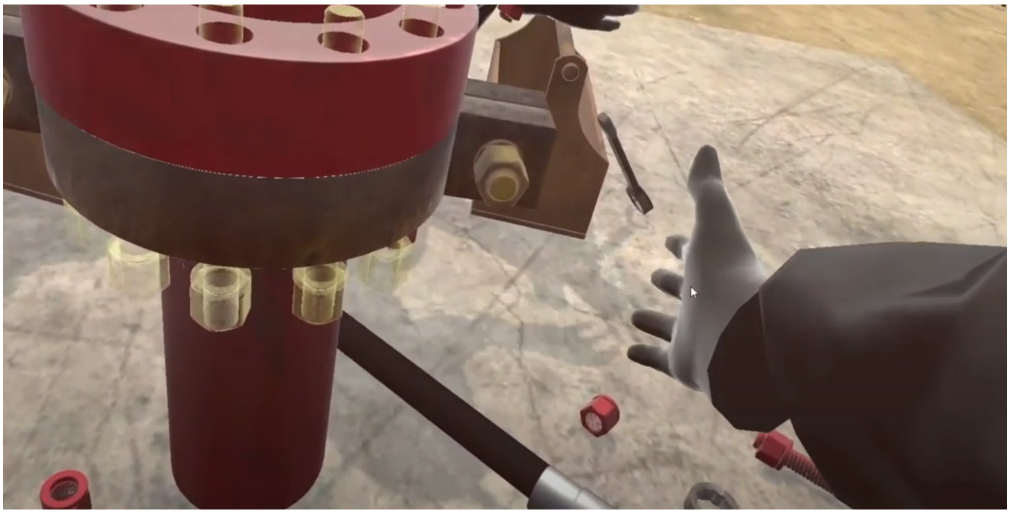


Figure 80 - *DreamPort - software*

6.10 FIRST AID VR

First-aid simulator (First Aid VR, s.a.) using the HTC Vive and Oculus Rift/Quest technologies. It includes various scenarios such as CPR, burns treatment, snake bite, rescue of a toddler, etc. It works with a CPR manikin (the manufacturer offers two models of manikins [without further specification of features] providing greater training data feedback; however, based on the information available, other manikins can also be used).

HW requirements: Display device – headset (compatible with HTC VIVE, Oculus Rift and Oculus Quest). An existing CPR manikin can also be used.

Price: Unknown.

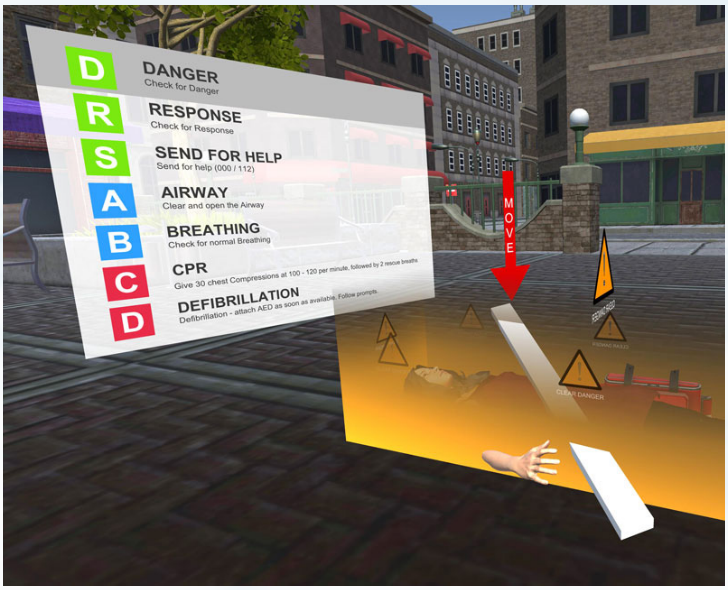


Figure 81 - *First Aid VR - software*

Figure 82 - *First Aid VR - software*

6.11 V-ARMED

A comprehensive technology solution by V-Armed (V-Armed, 2021) which is currently offered mainly to armed security forces; in principle, however, it could be successfully used by FRS CR, too. The tool allows up to 10 users to perform a specified task in the VR, which can also be checked directly by the supervisor.

Figure 83 - *V-Armed*

The software can realistically display and calculate the current development in the scene for all the participating users. It also gives the supervisor the possibility to actively influence development of the scenario (behaviour of victims, weather, etc.) and to view the intervention from diverse angles. For the simulator to work properly, a sufficient space must be ensured in which users will move around because the software allows users to cross a relatively large area, for example to walk to other rooms. After completion of each scenario, the supervisor can review the actions and assess their correctness in a given situation. The SCE tool enables creation of model scenarios.

V-ARMED creates custom 3D VR simulations for large-scale training. The life-like multi player scenarios enhance mission readiness and situational awareness for defence, law enforcement, first-responder and engineering teams.

For practical use by FRS, some of the software components need to be modified, for example by modelling fires, hazardous substance release, etc. Using this simulator, FPUs could train for example movement at the scene of a fire, evacuation of victims from a scene of a fire, or team cooperation in the event of a traffic accident or hazardous substance release.

HW requirements: The technological solution consists of wireless sets comprising a headset, real-world objects equipped with trackers, a "6DOF" tracking base (area of up to 60x60 m) and a powerful VR station (compatible with Dell laptops) and portable batteries stored in a "backpack" that connects a user's device.

Price: Unknown.

Figure 84 - *V-Armed Supervisor*

6.12 STREET SMARTS VR

The Street Smarts VR solution (Street Smarts VR, 2019) is currently used also mainly for armed security forces, and its design is very similar to V-Armed. The system consists of an HTC headset, two operating devices and tracking towers. Street Smarts is designed primarily for police forces and provides training of fast response to sudden changes in an emergency situation. After the necessary modifications, the solution could be used by FRS for instance to train evacuation of persons and animals, or to fulfil population protection tasks.

The platform includes software that is licensed to individual users. It also includes regular content updates that provide new training scenarios. The scenarios are sourced from real life, from actual bodycam footage to incident reports.

Street Smarts VR is designed to build resilience and maximize preparedness to any situation. In addition to the existing scenarios, new content from the real world requested by the respondent community is regularly released.

Each training scenario has been optimized to generate nine outputs in order to provide the participants with a diverse set of experiences and at the same time to simplify execution and analysis for the trainers. Instructors can intervene at critical branches, opting for example to have a subject comply with commands, or attack.

HW requirements: The solution requires HTC VIVE Pro headset, HTC VIVE trackers, Dell Precision 5820 Tower computer and USB-C monitor. The device is supplied with the Pelican 1615 Air Case. However, as this is a tailor-made package, the hardware requirements are indicative only.

Price: Unspecified. The company offers tailor-made packages, i.e. the price is calculated based on the customer's requirements.

Figure 85 - *Street Smarts VR*

6.13 RESCUE ASSIST APP

Mercedes-Benz (Mercedes-Benz, s.a.) developed software that provides key information. After scanning the relevant QR code with a smartphone or tablet camera the correct Rescue Card opens for the given Mercedes-Benz vehicle that has had an accident or that is on fire. The Mercedes-Benz Rescue Assist application then displays the location of all components relevant for the FPU such as airbags, batteries, power and fuel lines, plus the tanks for fuel, oil and gas. High-voltage components are also shown clearly in the case of electric and hybrid vehicles. The application can project the above components directly in the real-world image.

HW requirements: Only a smartphone or tablet is required to use the application.

Price: Free of charge.

Figure 86 - *Rescue Assist App*

6.14 EDGYBEES

In tactical and operational emergency management, the Edgybees technology solution (Edgybees, 2021) allows the response commander to immediately evaluate the emergency using an augmented reality technology based on real-time data sharing. Edgybees augments live video feeds from unmanned aerial vehicles with geo-information layers, infrastructure, building layouts, unit locations and other data layers. The platform has been recently used during wildfires in Australia and California (the drone feeds were used to plan the evacuation routes).

HW requirements: The solution requires the use of camera-mounted commercial unmanned aerial vehicles (drones). Furthermore, a display device is needed to which the flight data are streamed and where they are mixed with other data layers.

Price: Unknown.

Figure 87 - *Egdybees*

6.15 BLACK MARBLE

Black Marble (Black Marble, 2021) has come up with an MR software solution for police investigation. The software cooperates with the Holo Lens 2 MR set and allows the users to scan their surroundings, record the exact location of individual objects for further analysis, make photos, videos or audio recordings, place virtual objects around them and to view the up to-date information in real time.

Subject to minor modifications, this technology solution could be used by investigators of the FRS CR to identify causes of fire.

HW requirements: The solution is compatible with Microsoft HoloLens 2 glasses. No other hardware is known to be required.

Price: Unknown.

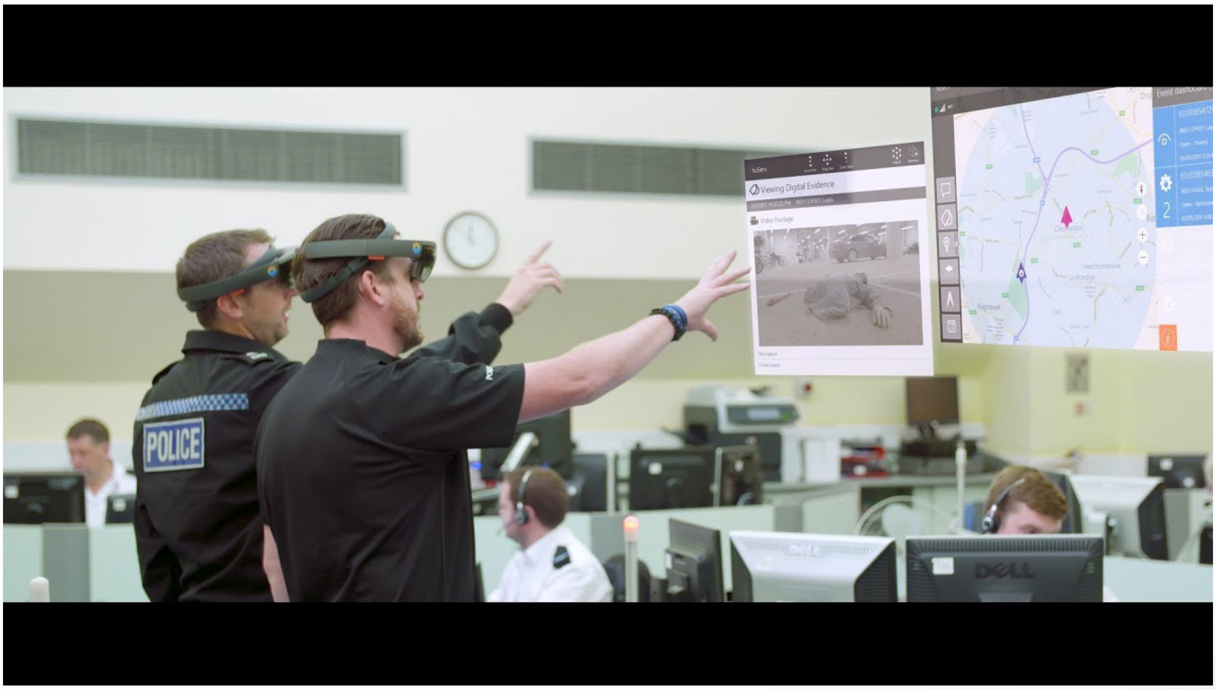


Figure 88 - *Hololens 2 and Black Marble SW*

6.16 BOEING INEXA CONTROL

Boeing (Boeing, 1995) presented a technology that allows the response commander's team to evaluate the progression of wildfires in difficult terrain using mixed reality. Unmanned aerial vehicles use infrared cameras and other sensors to provide a real-time map of a fire's progress as well as the location of any teams fighting fires on the ground and in the air.

Boeing made its 2D mapping system known as INEXA Control, compatible with Microsoft's Hololens augmented reality headset. That allows for a 3D map that gives a bird's-eye view of the situation and even allows for the controlling of drone paths through the software.

HW requirements: Microsoft HoloLens glasses.

Price: Unknown.

Figure 89 - *Hololens and BOEING Inexa Control*

6.17 PHIAR AR NAVIGATION

This application by Phiar Technologies Inc. (Phiar Technologies, 2020) uses augmented reality for driving navigation. The application is currently being developed. It should be possible to use the application on a tablet, smartphone or car infotainment system (if they are equipped with a camera).

Unlike standard navigation systems, this application uses the camera to show you the real world, while displaying digital information (especially the route and time to destination; however, it should also be able to show the speed, distance from the vehicle ahead, etc.).

HW requirements: Camera-equipped tablet, smartphone or infotainment system.

Price: Unknown.

Figure 90 - *Demo of the Phiar application*

Figure 91 - *Application in the infotainment system*

6.18 SMARTCAM 3D VIEW

Rapid Imaging (Rapid Imaging, 2021) developed the SmartCam3D® geographical software which cooperates with commonly available unmanned aerial vehicles by DJI to provide the operator with augmented reality overlays including the key virtual information, for instance after floods, earthquakes or landslides. This can be used for example for mapping of missing structures, flooded roads, mobile phone signals of victims and response units, etc. Use of this technology can therefore make deployment of FPUs much more effective during rescue and recovery activities.

HW requirements: The solution requires the use of a camera-mounted unmanned aerial vehicle (drone). Furthermore, an unspecified display device is required.

Price: Purchase price of the licence:

- Monthly licence for professionals – USD 80 (approx. CZK 1,800);
- Annual licence for professionals – USD 800 (approx. CZK 18,000);
- Free trial version available.

Figure 92 - *Smart Cam 3D view*

7. SUMMARY OF KEY FINDINGS

Based on identification of the application areas in which VR/AR/MR could be potentially used by FRS CR (i.e. Chapter 5) and the corresponding solutions (i.e. Chapter 6) the following overview has been made – Table 7. The overview shows which of the identified needs can be currently covered by the available solutions.

Table. 7: *Classification of the identified VR/AR/MR solutions depending on the activity segment of FRS CR*

IDENTIFIED SOLUTION		TARGET GROUPS			NOTE
		FRS CR and FPU members	**Population**	**Professional public**	
1	Flaim Trainer	**VR**	-	-	FPU
2	Flaim Extinguisher	-	**VR**	-	Fire prevention
3	Ludus Fire Safety	-	**VR**	-	Fire prevention
4	RiVR Investigate	**VR**	-	-	Investigation of causes of fire
5	Rosenbauer ALTS + Cage	**VR**	-	-	FPU
6	Coal Services	**VR**	-	-	FPU
7	Dreamport – simulator of actions in case of fire	-	**VR**	-	Fire prevention
8	Dreamport – Working at height simulator	**VR**	-	-	FPU
9	Dreamport – Simulator for elimina-tion of oil, water or gas leakage	**VR**	-	-	FPU
10	First Aid VR	**VR**	**VR**	-	FPU
11	V-Armed	**VR**	-	-	FPU
12	Street Smarts VR	**AR**	-	-	FPU
13	Rescue Assist App	**AR**	-	-	FPU, IRS
14	Edgybees	**AR**	-	-	Intervention commanders, Operations and Information Centres, population protecti-on and crisis management
15	Black Marble	**AR/MR**	-	**AR/MR**	Fire prevention
16	Boeing Inexa Control	**MR**	-	**MR**	Population protection and crisis management
17	Phiar AR Navigation	**AR**	-	-	FPU
18	SmartCam 3D View	**AR**	-	**AR**	Operations and Information Centres, population protecti-on and crisis management

With regard to the identified approaches, we can provide the following findings and best practice examples, which present a significant potential for development of the area under consideration:

- It must be noted that none of the identified solutions should be adopted and applied immediately without modifications. Although the solutions are affordable, user modifications and the resulting ad hoc costs must be taken into account. It is also important that the potential areas of application identified in Chapter 5 have not been adequately covered by the commercially available and marketed solutions. Therefore, purchasing a product without considering the specific needs of the client (FRS CR) cannot be viable.
- It can be expected that development of this area will be primarily determined by the degree of autonomy that FRS CR will get to independently produce/modify the VR/AR/MR solutions rather than by their commercial availability. However, it is not likely that FRS CR could act with full autonomy. It is therefore most probable that the organization will have to combine solution procurement and its own professional skills. It might be feasible to have a team of experts capable of at least programming in UNITY, 3D creation, object scanning, etc. The outputs produced within the organization would then be transformed into specific VR/AR/MR solutions within the purchase/public procurement process. In cases where the delivery of such VR/AR/MR solutions also includes the relevant engine, any required modifications could be made by the organization itself.
- Training in adapted premises:
  - Perform real simulations of "external conditions" (e.g. simulation of thermal discomfort or wind) to achieve an experience combining real and virtual perception. An added value of such simulations will be higher-quality immersive presence in the given reality.
  - Perform the training in biofeedback response suits (monitoring for example the heart rate, blood pressure, body temperature, lactate production). This should simulate the real situation during the experience and at the same time allow for monitoring and evaluation of physiological reactions to stressful situations. A more affordable alternative is to use response suits and separate sensors to monitor physiological reactions.
  - Use cooperative training of multiple participants in a given moment, which would strengthen the tactical training component and joint approach in problem solving/decision-making.
- Training in unadapted premises:
  - Use the virtual training ground, which means that multiple participants meet using VR – their physical presence at one place is not necessary (this would enable meeting of participants from various locations in the Czech Republic or abroad). This method can be used to train intervention tactics or response in model cooperative situations. It requires the use of a headset (currently this can be done for example with Oculus Quest II; wifi connection is required).

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