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COMPARISON OF REALITY TYPES

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Abstract: Rapid developments in technology reflect and directly affect all areas of life. One of these areas is reality technology. With this technology that combines the physical world with the digital world, changes can be created in humans' "reality" perception. This study presents information and detailed comparisons about the fundamentals, principles, and applications of augmented, virtual, and mixed reality technologies that have become popular recently.

Keywords: Augmented reality, virtual reality, mixed reality

Gerçeklik Türlerinin Karşılaştırılması

Özet: Teknolojideki hızlı gelişmeler, yaşamın her alanına yansımakta ve doğrudan etkilemektedir. Bu alanlardan birisi de gerçeklik teknolojisidir. Fiziksel dünyayı dijital dünya ile birleştiren bu teknolojiyle insanların "gerçeklik" algısında değişiklikler oluşturulabilmektedir. Gerçekleştirilen çalışmada son zamanlarda popüler hale gelen artırılmış, sanal ve karma gerçeklik teknolojilerinin temelleri, esasları, uygulamaları hakkında bilgiler sunularak ayrıntılı karşılaştırmalar yapılmıştır.

Anahtar Kelimeler: Artırılmış gerçeklik, sanal gerçeklik, karma gerçeklik

1. INTRODUCTION

People perceive and correlate the surrounding objects, namely the three-dimensional (3D) world, basically using their five physiological senses. The activation of different senses for an object (stimulation of different sensory organs) depicts its perception of reality in the 3D world. Afterward, reality; requires the presence, the possession of matter, and is perceived and experienced with the sense organs. The opposite concept is virtuality. Table 1 gives the definitions of "reality" and "virtual" concepts in some dictionaries (URL1-7, 2020).

Technological developments in recent years in electronics areas have led to significant changes in the computer world. The changes demonstrate increasing the processing speed of computers/microprocessors, expanding their memory capacities, decreasing their size, decreasing their costs, and more. As a result, operations such as obtaining, processing, transmitting, and saving real or virtual, single or multi-dimensional data have also become faster and easier. Such developments in computer-based technologies have also revealed different concepts of reality. Virtual environments have started to be used widely in many areas.

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Table 1. Definitions of "reality" and "virtual" terms in some dictionaries

Dictionary	Reality	Virtual
Oxford English https://www.lexico.com/	* "The state or quality of having existence or substance" * "Existence that is absolute, self-sufficient, or objective, and not subject to human decisions or conventions"	* "Not physically existing as such but made by software to appear to do so" * "Carried out, accessed, or stored by means of a computer, especially over a network"
Cambridge dictionary https://dictionary.cambridge.org/	* "The state of things as they are, rather than as they are imagined to be" * "A fact" * "The actual state of things, or the facts involved in such a state"	* "Something that is virtual can be done or seen using a computer and therefore without going anywhere or talking to anyone" * "Used to describe something that can be done or seen using computers or the internet instead of going to a place, meeting people in person, etc."
Longman Dictionary https://www.ldoceonline.com/	* "What actually happens or is true, not what is imagined or thought" * "The fact that something exists or is happening"	* "Very nearly a particular thing" * "Made, done, seen etc on the Internet or on a computer, rather than in the real-world"
Macmillan dictionary https://www.macmillandictionary.com/	* "The real character or nature of things, not what you imagine or think is possible" * "A fact, event, or situation as it really exists reality of"	* "Almost the same as the thing that is mentioned" * "Created by computers, or appearing on computers or the internet"
https://www.dictionary.com/	* "The state or quality of being real" * "Something that exists independently of ideas concerning it" * "Something that exists independently of all other things and from which all other things derive"	* "Having the essence or effect but not the appearance or form of" * "Of or relating to a computer technique by which a person, wearing a headset or mask, has the experience of being in an environment created by the computer, and of interacting with and causing changes in it"
https://www.oxfordlearnersdictionaries.com/	"A thing that is actually experienced or seen, in contrast to what people might imagine"	"Made to appear to exist by the use of computer software, for example on the internet"

A new trend of augmented reality (AR), virtual reality (VR), and mixed/merged reality (MR) have started recently. In a rapidly changing society where there is a lot of information and knowledge available, there is a need to adopt and apply information at the right time and place to achieve key competence in both school and business settings. The entertainment industry is currently focusing on using new applications and games based on a virtual environment to embrace the mass market. Advancements in computer technology have made 3D graphic production and representation smoother and more comfortable to apply (Portalés et al., 2009).

Several studies have been carried out on AR, VR, and MR technologies, and different survey categories have been established concerning the technology (Azuma, 1997; Costanza et al., 2009; Zhao, 2009; Berryman, 2012; Billinghurst et al., 2015). Angulo and Velasco (2013) described a VR immersive environment used as a tool to assist the design of architectural spatial experiences. Yoshida et al. (2014) presented a VR surgical education system in which an HMD and finger tracking used to demonstrate the expert's precise finger movements during surgery for practitioners. Onime et al. (2015) proposed an AR application as an effective way of teaching microelectronics in laboratories for engineering students. Chen et al. (2016) used an AR-based video-modeling storybook to strengthen and attract children with ASD. Tuli and Mantri (2015) showed how AR could be used in chemistry labs to enhance students' learning experience. Odeh et al. (2013) discussed the compatibility of AR in remote labs. The remote AR lab enables the engineering students to interact and perform their experiments with the experimental setup located at some other place. Students can easily access and control the lab's equipment remotely through the internet. Huang et al. (2019) compared AR and VR technologies regarding their effect on learning outcomes. Costanza et al. (2009) performed a detailed review of related MR applications as well as the solutions and limitations available to develop such applications pragmatically. Stretton et al. (2018) created an overall view of the

particular use of MR applications in healthcare. Hashimoto et al. (2007) implemented an MR visualizing system to decrease the risk of traffic accidents by showing the blind corners for drivers. In this application, MR see-through devices are used by the driver. This app improves the real environment by making the hidden objects unhidden to the user.

The objectives of this paper are to explain "augmented reality," "virtual reality," and "mixed reality," classify the differences and similarities between AR, VR, and MR, and compare each one technology with advantages and disadvantages.

2. REALITY TYPES

Many people define reality as the things we can see or interact with through our eyes and other senses. We all know that human beings cannot see everything, so we cannot limit reality to things we can see or touch. We can only become aware of reality through our senses, so we can only define our perception of reality. From this perspective, we can tight reality to the physical space in which we are. Even though the outside world is real, the reality is limited to things that can be seen or experienced at the moment. The rest is a part of our imagination.

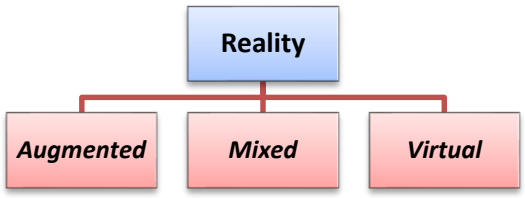


Figure 1:
The types of reality

Reality is divided into three types; virtual, augmented, and mixed, as shown in Figure 1. Various definitions are made to describe different types of reality. A standard definition is a model presented by Milgram et al. (1995), which describes a continuum and a stepwise transition, as shown in Figure 2.

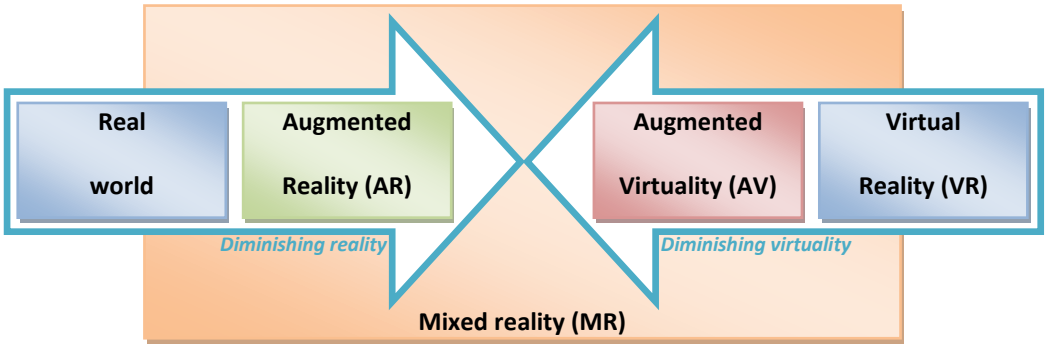


Figure 2:
Reality-virtuality continuum

The reality-virtuality continuum is a scale that varies between the entirely virtual virtuality and the thoroughly real reality. In other words, it contains all the real and virtual objects/items and compositions. The extreme left of the continuum includes only real objects (real environment). In contrast, the extreme right includes only virtual objects (virtual environment). In-between them, there is the MR area (augmented reality-virtuality).

The continuum indicates two different types of MR, namely augmented reality (AR) and augmented virtuality (AV) (Figure 3). In AV, the environment contains more virtual objects/items than the real ones. By nature, the continuum's center represents a state of balance between real and virtual objects/items. However, Milgram et al. (1995) refer this to a hypothetical situation where the real-world blends perfectly with the virtual world. Moving along the continuum from left to right represents a decreasing reality (or real objects/items) and increased virtuality (virtual objects/items), and at the point of VR, there are no real objects anymore (Milgram et al., 1995).

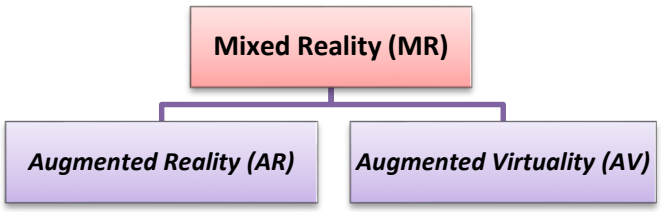


Figure 3:
The types of mixed reality

Table 2 gives the definitions of "augmented reality" and "virtual reality" concepts in some dictionaries (URL1-7, 2020).

Table 2. AR and VR definitions in some dictionaries

Dictionary	Augmented reality (AR)	Virtual reality (VR)
Oxford English https://www.lexico.com/	"A technology that superimposes a computer-generated image on a user's view of the real-world, thus providing a composite view"	"The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors"
Cambridge dictionary https://dictionary.cambridge.org/	"Images produced by a computer and used together with a view of the real world"	"A set of images and sounds, produced by a computer, that seem to represent a place or a situation that a person can take part in"
Longman Dictionary https://www.ldoceonline.com/	"A situation in which computer-generated information, images etc are combined with things in the real-world or images of real things"	"An environment produced by a computer that looks and seems real to the person experiencing it"
Macmillan dictionary https://www.macmillandictionary.com/	"The technology of putting images or information produced by a computer on top of a real view, image, video etc so that the user can see both at the same time"	"Images and sounds that are produced by a computer and connected equipment to make the user feel as if they are in real three-dimensional space"
https://www.dictionary.com/	* "An enhanced image or environment as viewed on a screen or other display, produced by overlaying computer-generated images, sounds, or other data on a real-world environment" * "A system or technology used to produce an enhanced environment" * "An artificial environment created through the combination of real-world and computer-generated data"	* "A realistic and immersive computer simulation of a three-dimensional environment, created using interactive software and hardware, and experienced or controlled by movement of the body" * "A computer-generated environment that, to the person experiencing it, closely resembles reality"
https://www.oxfordlearnersdictionaries.com/	"A technology that combines computer-generated images on a screen with the real object or scene that you are looking at"	"Images and sounds created by a computer that seem almost real to the user, who can interact with them by using sensors"
https://www.collinsdictionary.com/	"An artificial environment created through the combination of real-world and computer-generated data"	"An environment which is produced by a computer and seems very like reality to the person experiencing it"

2.1. Augmented Reality

Augmented reality was introduced to the world in the 1960s era and remained a growing research area since. However, it was not considered as a research area until the 1990s. AR has many definitions/descriptions, and many of them reflect the use in a particular area or context (URL8, 2020).

Recalling Figure 2 it is seen that AR is on a spectrum between reality and virtuality. Azuma defined AR as a variation of virtual environments. Virtual environment technologies completely immerse users within an artificial environment. During the immersion, the users cannot see the real-world. On the other hand, AR allows the users to see both the real and virtual worlds where the virtual objects/items overlapped or compounded with the real world. AR "supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space" (Azuma, 1997).

Milgram also positioned AR as an enhanced (augmented) view of the physical world using computer-generated or digital data (Milgram et al., 2016). The third definition in a magazine published by Boeing in which Memi defines AR as "a machine vision and computer-graphics technology that overlays graphic additions on views of the real-world. The hallmark of AR is that the graphics are spatially registered; that is, they are positioned in the viewed scene relative to the positions of actual objects." (Memi, 2006). In this definition, AR is confined to graphical additions to the real-world. Azuma argues that AR might be applied to all senses and does not need to be limited to visual additions. Researchers have focused on "blending real and virtual images and graphics." However, AR could be extended to include sound. "Another example is haptics. Gloves with devices that provide tactile feedback might augment real forces in the environment." Same time Azuma defines AR as systems with bellowing three essential characteristics (Azuma, 1997):

i. Combination of real and virtual,
ii. Real-time interaction,
iii. Registration in three dimensions (3D).

Azuma further argues that AR can add objects to the real-world and the possibility to remove them. In one example, the user uses a real paddle to handle furniture models in a typical interior design application. By pushing, tilting, moving, and other movements, the user can select furniture pieces, drop them into a room, push them to the desired locations, and remove them from the room (Azuma et al., 2001).

Some application areas of AR are as follows: Medical, tourism, military, navigation and path planning, manufacturing, entertainments and games, visualization, robotics, media, education, business, marketing, arts, urban planning, geospatial, civil engineering, etc. (Mekni and Lemieux, 2014).

2.2. Virtual Reality

Howard Rheingold (1991) defines VR as an experience in which a person is "surrounded by a 3D computer-generated representation, and can move around in the virtual world and see it from different angles, reach into it, grab it, and reshape it." In VR, users are immersed and able to interact with 3D worlds. The user has to feel like he is actually inside the virtual world. The VR has to be the user's alternative reality (Janssen, 2011).

According to Coates (1992), VR is "electronic simulations of environments experienced via head-mounted eye goggles and wired clothing, enabling the end-user to interact in realistic 3D situations" (Steuer, 1993). Dynamically engaging the user is essential to make VR reality cognitive because the user is an active and cognitive participant in the virtual environment where his natural behavior produces an immediate and observable effect. In this case, in a digitally generated virtual world, space, or environment, the user can undergo an immersion or

psychological experience to lose himself in it. Also, VR systems are generally divided into three according to the degree of immersion provided, as in Figure 4 (Onime et al., 2015).

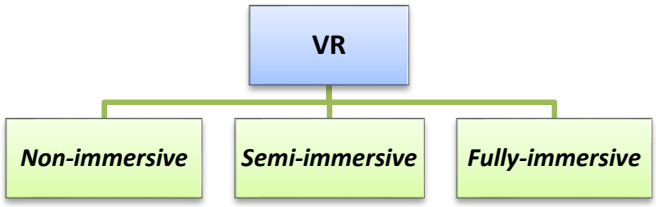


Figure 4:
The types of VR systems

Some application areas of VR are as follows: Medicine/healthcare, tourism, sports, rehabilitation, architecture, virtual travel, gaming, movies, TV, etc. Also, the general stages of AR/VR development are given in Figure 5.

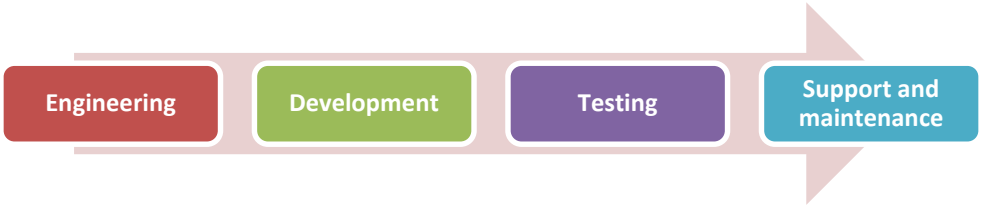


Figure 5:
The stages of AR/VR development

2.3. Mixed Reality

As shown in Figure 2, MR is in the middle of reality and virtuality. There are two types of MR, AR, and AV. The user is placed in an interactive setting; in AR, the surrounded environment is real with virtual asset augmentation. In contrast, AV's surrounded environment is virtual with real-world augmentation (Hughes et al., 2005).

MR presents a unique challenge in combining the interacting factors, display controls, graphics, audio presentations, and human interaction in one unified system. Different types of AR/MR applications are studied by many researchers in various industries, such as education, entertainment, and healthcare (O'Connor et al., 2005).

Generally, the MR platform consists of hardware and software environments (Figure 6). While processor, display, camera, microphone, GPS, 6-DOF tracking sensor, smartphones, AR glasses, headsets, etc. are used in the hardware environment, the software environment consists of four layers: the base platform layer, the MR platform layer, the application layer, and the contents layer (State et al., 1996; Uchiyama et al., 2002; URL18, 2020).

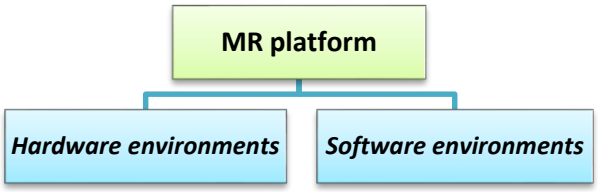


Figure 6:
The structure of the MR platform

Some application areas of MR are as follows: Training, rehabilitation, surgical field, manufacturing operators of service maintenance, etc.

3. COMPARISONS

3.1. Similarities of AR and VR

The basic similarities of AR and VR are summarized below:

i. Generally, they serve the same purpose to its users: enhanced or enriched experience
ii. They deliver an improved experience overall
iii. They have the marvelous potential for applications in many areas
iv. They have the same core programming.

3.2. Differences between AR and VR

The primary differences between AR and VR are summarized below (Berryman, 2012; Kounavis et al., 2012; Střelák, 2016; URL19, 2020):

i. In VR, the user is completely immersed in a virtual environment and is isolated from real life. In contrast, even if there are some virtual additions in AR, the user can still touch the real-world.
ii. AR is built on real-life and makes it more interactive, while VR is built on a completely virtual world.
iii. In AR, real life is not replaced with a virtual environment; the used environment is an enhanced view of reality. In contrast, in VR, the environment is recreated and completely simulated, and it does not exist.
iv. Using AR applications is just like using any mobile applications. In contrast, in VR applications, devices such as HTC Vive, Google Cardboard, and Oculus Rift are needed to cover the user's entire field of view and control what he sees and hears.

3.3. Advantages of AR

Some advantages of AR are summarized below (Azuma, 1997; Hsiao et Rashvand, 2011; Çetinkaya and Akçay, 2013; İbili and Şahin, 2013; URL9-10, 2020):

i. It offers personalized learning.
ii. It enhances the learning process.
iii. Detailed information about the real-world physical environment can be provided to people through a visual or text by using various technologies (phone, tablet, virtual glasses, etc.).
iv. They are used in many fields like education, medical, military aircraft, entertainment, etc.
v. It brings dynamism and a realistic feel to the applications and objects it uses.
vi. In the commercial sector, people have the opportunity to try objects in the same environments.
vii. Increase student motivation and problem-solving ability.
viii. Abstract concepts can be embodied using AR like geometry subjects.
ix. It enriches topics with 2D models, 3D models, animations, and videos.
x. Users can share their experiences in long places.
xi. It helps develop applications that provide users with "real" experience.

3.4. Advantages of VR

Some advantages of VR are summarized below (URL10-12, 2020):

i. Immersive learning environment.
ii. The user will experience a computer-generated World of imagery and sounds.
iii. In VR, an interactive environment is created.
iv. It helps students develop their imagination, creativity and collaboration.
v. Providing the opportunity to create a realistic world where users can explore the world.

3.5. Disadvantages of AR

Some disadvantages of AR are summarized below (İbili and Şahin, 2013; URL13-14, 2020):

i. The devices available for building the AR applications lack good hardware features, which cause some restrictions. Memory, graphics power, processor capability, internet capability, and similar items should be sufficient in device.
ii. Environmental conditions like light and noise could negatively affect AR applications.
iii. The software error of the programs using AR may be due to technological product errors.
iv. Sometime limitations can prevent the application from working correctly.
v. The users should know the use of technological tools (Google Glass, HoloLens, etc.) to be used along with the AR applications.
vi. The devices that are used with the AR applications have high financial value.
vii. AR can cause mental health problems.
viii. Lack of security can affect the AR principle.

3.6. Disadvantages of VR

Some disadvantages of VR are summarized below (Nedic et al., 2003; URL15, 2020):

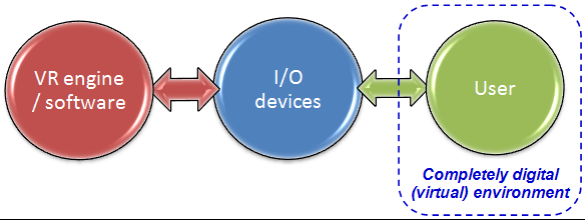
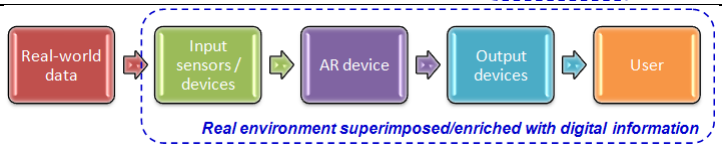
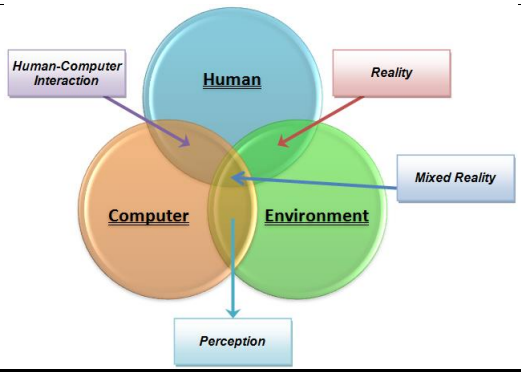
i. Although VR is becoming common these days, programmers will never achieve an interaction with the virtual environments.
ii. Escape is standard among those using VR environments. Users choose to stay in the virtual world rather than dealing with real-world problems.
iii. Dealing with the virtual environment will never be like dealing with the real one. That means if the user could achieve a task using the virtual environment this will not guarantee his ability to do the same in real life.

General comparison of reality types are given in Table 3 (Carmigniani et al, 2011; Bamodu and Ye, 2013; Billinghurst et al., 2015; McMillan et al., 2017; Farshid et al., 2018; Li et al., 2019; Rokhsaritalemi et al., 2020; URL8, 2020; URL16-19, 2020).

Table 3. General comparison of reality types

Properties	**Virtual reality**	**Augmented reality**	**Mixed reality**
	VR	**AR**	**MR**
World	Representation of the real-world with digital data and information	Data and information superimposed on the real-world	Entry of possible information and data into the real-world
Environment	Fully artificial/digital/virtual	Virtual objects/items over the real-world	Combination of virtual and real-world
Immersion	Fully virtual world	Augmenting real-world	Real time spatial mapping for merging real and virtual world
Concept	Creating a perception of presence and full immersion	Supporting the real environment, add utility to physical co-presence	Adaptation of actual events
Perceiving the environment	No longer perceives the real environment	Still sees the real environment, besides receives additional information	Still sees the real environment, and the virtual objects become part of the

			displayed	real-world
Experience		Can only experience the digital 3D world with special auxiliary tools	Can experience with simpler utility tools	Can experience with conducive tools such as transparent glass and LCD
Rate		Virtual (very)+real(little)	Virtual (little)+real(very)	Virtual (middle)+real(middle)
Attribute		Virtual	Both virtual and reality	Mix
Information	Registered in 3D space	Yes	Annotated in 3D space	Yes
	Correlation to user space	No	No	Yes
	Time persistence	No	No	Yes
Interaction		With virtual object	With physical object	With physical and virtual object
Display device		Special headset, smart glasses	Headsets (optional)	Headsets (optional)
Image source		Computer-generated graphics/images	Combination of computer-generated graphics/images and real-life objects/items	Combination of computer-generated graphics/images and real-life objects/items
Perspective		The position and size of virtual objects/items change according to the user's perspective in the virtual world	Virtual objects/items react according to the user's real-world perspective	Virtual objects/items react according to the user's real-world perspective
Presence		There is a feeling of being transported somewhere, but not a real-world feeling	Feeling of being in the real-world, but with new objects/items superimposed in the transported somewhere	Feeling of being in the real-world, but with new objects/items superimposed in the transported somewhere
Awareness		Virtual objects/items that are indistinguishable from reality	Virtual objects/items defined according to user behavior	Virtual objects/items that are indistinguishable from reality
Input		Joysticks, controller wands, data gloves, balls/tracking balls, trackpads, buttons, motion trackers, on-device control, treadmills , audio input, bodysuits, motion platforms (virtual omni), hand worn devices and bare hand input.	2D user interfaces (mouse, keyboard, pointing device, etc.), 3D and multimodal interfaces (glove, wireless wristband, handheld wands, speech, gesture, etc.)	6-DOF tracking sensor, audio input, cameras, motion trackers and controllers and gaze/gesture/voice recognition devices.
Interaction tools		Wearable-sensor device-based input (data gloves, inertial sensor and myoelectricity (EMG) sensor), touch device-based input (touch screen and stylus pen), and computer vision interaction device-based input	Information browsers, 3D-tangible-natural user interfaces, collaborative interfaces, multimodal interfaces, hybrid interfaces	Graspable interfaces
Output (display)		Video display monitor, head- and ear-mounted equipment, stereo display monitor and projection displays (CAVE-type, fishbowl VR and IDesk/IScreen)	Video and projection based displays, optical see-through displays, eye multiplexed displays, head mounted displays (HMD, head-attached displays), handheld and body-attached displays, spatial displays, other sensory displays	Head-up display, cave automatic virtual environment, head-mounted display, computer - tablet - mobile phone - handhelp PC
Development tools		Unity, Amazon Sumerian, Unreal Engine, CryEngine, Blender, 3ds MAx, SketchUp Studio, Maya, Oculus Medium, Lumberyard	Unity, Amazon Sumerian, ARToolkit, osgART, Studierstube, MXR-ToolKit, FLARManager, Processing, D'Fusion, Metaio Creator, OpenFrameworks, DART, Wikitude Studio, Vuforia and Metaio Unity plug-ins, EasyAR, Layar Creator, ARKit, AR-Media plug-ins, ARCore, Maxst, BuildAR	Unity, MRTK, ARToolkit, Layar, Vuforia, Zapbox, Kudan, Wikitude, OSVR
Usage areas		Health care, safety, military, education,	Education, military, navigation, advertising and marketing, industrial/interior	Education, simulation-based learning (SBL), Interactive product content management

		design, tourism and travel, emergency management/search and rescue, healthcare planning, practice and education, broadcast and live events, translation, music, games, social interaction	(IPCM), military, remote working, functional mockup, engineering, entertainment and education, medical,
Examples	Oculus Rift, Sony Headset VR	Google Glass, Pokemon Go	Microsoft HollowLens MR
VR			
AR			
MR			

4. CONCLUSIONS

This paper scans previously published papers to suggest a comprehensive framework that includes the various components of AR, VR, and MR applications. The framework comprises an explanation of reality types; AR, VR, and MR, and simultaneously discusses the similarities and differences between AR and VR. It also proposes the advantages and disadvantages of both AR and VR and compares reality types in many ways. As development continues on virtual and MR devices and technologies, it seems logical to expect more AR, VR, and MR technologies into our lives.

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