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Review Article

The Mixed Reality Revolution - Opportunities and Challenges

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Abstract

Developments in a portfolio of enabling digital technologies which include imaging, wireless, visualization, computing, mobile and wearable technologies are creating environments and experiences which blend and blur the boundaries between real and virtual worlds. These developments present many opportunities and challenges for almost all sectors of human activity. This editorial seeks to explore and reflect on the past, present and future of mixed reality in order to speculate on the likely impact of the mixed reality revolution.

Keywords: Mixed Reality; Augmented Reality; Virtual Environments; Immersive Technologies; Virtual Reality; Digital Imaging

Introduction and Background

Mixed Reality is a concept that blends real-world, real-time physical environments and artefacts with computer-generated artificial environments and artefacts. The term mixed reality was first defined in 1994 by Paul Milgram and Fumio Kishino [1]... anywhere between the extrema of the virtuality continuum" (VC), where the virtuality continuum extends from the completely real through to the completely virtual environment, with augmented reality and augmented virtuality ranging between (Wikipedia - https://en.wikipedia.org/wiki/Mixed_reality).

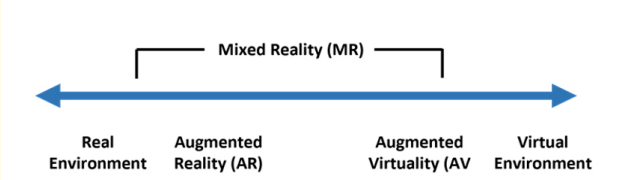

Figure 1: The Mixed Reality Spectrum (Licenced by author).

Mixed Reality in this definition is conceived as being the central section of a continuum which has totally real-world, real-time environments at one end of the spectrum and totally artificial, synthetic environments at the other end (Figure 1). Mixed Reality is neither wholly real nor wholly virtual. This would therefore include Augmented Reality (AR) in which the physical world is overlaid with synthetic objects and information and Augmented Virtuality (AV) in which virtual environments are enhanced by the presence or representation of physical artefacts or environments.

In discussing the Mixed Reality Revolution and its opportunities and challenges, this paper looks beyond the way in which mixed reality applications are being enabled and shaped by developments in disruptive digital technologies. This paper seeks to understand and reflect on the human drivers behind the desire or need for mixed reality applications. In understanding why and how we use mixed reality, we may be better placed to predict likely future developments and their impact across different sectors and application areas.

The human drivers behind mixed reality

The real-time physical world in which human beings exist is largely based on entirely predictable properties and behaviours. From the time we are born, our own actions, behaviours and understanding of the physical world comes from either exploring and experimenting or from accumulated knowledge passed on to us by other humans. For the majority of human history, our actions have been determined or constrained by the "Here and Now". What differentiates human beings (and arguably all living creatures) is our perception of reality which is based not just on the physical properties and behaviours of the real-time "real world" but also on our past experiences, creativity and imagination.

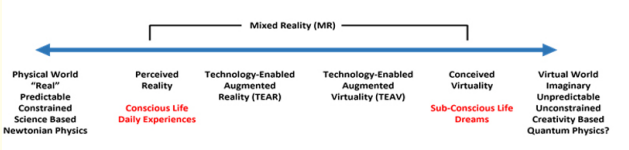

Figure 2: The Mixed Reality Continuum (licenced by Author).

This new visualization shown in figure 2 is a continuum which stretches from a physical world which is totally predictable and constrained in its behaviours to a virtual world which is totally unpredictable, imaginary and unconstrained is designed to bring an understanding of the nature of mixed reality and the impact of technology.

In this suggested new model, mixed reality stretches from perceived reality to conceived virtuality. Perceived reality is what we consciously experience in our daily lives. It is real and tangible but it is overlaid, augmented or influenced by our individual perceptions, experiences, attitudes and imagination. What we think of as physical reality is individual and personalized and is a mixture of the physical world and our very human qualities.

In this model, the other end of the spectrum I have described as conceived virtuality, created in our own minds and sub-conscious thoughts. It is a form of mixed reality because it blends in and is influenced by real-world artefacts and behaviours. It is essentially not (and can never be) a virtual world beyond our imagination.

Throughout history, mankind has sought not only to understand the physical world and it attributes and behaviours but also to overcome the constraints of time and space to build a different and better world. All human development and advances in civilization can be linked to a motivation to break the barriers of the physical world through innovation, creativity and imagination. Using this argument, we can begin to understand the importance of mixed reality in shaping the world we live in and the impact of enabling digital technologies in accelerating the rate of change exponentially.

Neuroscience and mixed reality

The workings of the human brain are an important factor in being able to assess the characteristics and impact of the mixed reality revolution. When we are developing the technologies which can augment both perceived reality and conceived virtuality, it helps if we know something about how our brains process data from both the "Real, Physical World" and an "Imaginary, Virtual World".

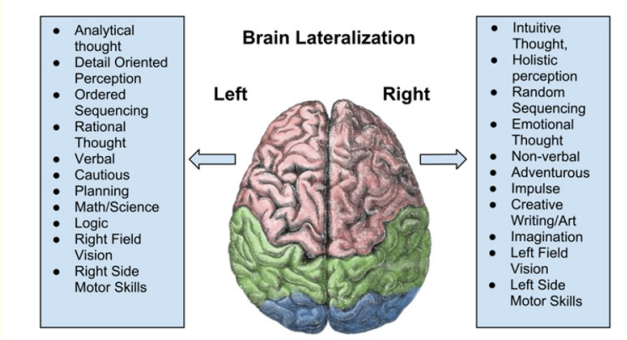

Figure 3: Brain visualisation (licenced under creative commons - https://www.pngkey.com/maxpic/u2w7a9r5u2r5q8i1/).

Figure 3 shows a visualization of the functions of the left side and right side of the brain. The left side of the brain is what is traditionally associated with scientists and mathematicians. It handles the logic and reasoning elements of the brain whilst the right side of the brain is associated with creative thinking and imagination. The left side of the brain has the characteristics linked to Newtonian Physics and Mathematics which relate to the physical world. This side of the brain is critical to precision engineering of the artefacts and devices we use on a daily basis.

The right side of the brain is unconstrained by logic and reasoning and empowers our imagination, creativity and spontaneity. It is therefore arguable that although we use both sides of our brain in our daily life, in our conscious waking hours, we tend to use the left side of the brain to perceive real world whilst, when we are asleep or dreaming, the right side of the brain stimulates our thought processes.

In other words, the left side of the brain develops to make sense of the real, physical world whilst the right side of the brain creates virtual environments and scenarios. This implies that human beings have always existed in a form of mixed reality and prior to the technologies which form the basis of this article, humans experienced both augmented reality and augmented virtuality. Before the digital age, augmented reality and augmented virtuality were both self-mediated as we overlaid the real world with our perceptions, knowledge and experience to create augmented reality whilst our imaginary virtual worlds were also influenced by the physical world to experience augmented virtuality.

The evolution of mixed reality

Using the arguments outlined in the previous sections, mixed reality as a concept is as old as mankind. From the moment we are born we use our five senses of sight, touch, hearing, smell and taste to experience physical world reality. We are also born with a genetic legacy which augments the five senses to deliver a perceived reality which is unique to the individual. Self-mediated augmented reality is a form of mixed reality which evolves and develops as we grow older and have education and life experiences which shape our perception of physical-world reality.

This form of augmented reality can also be mediated by other sources of data in the form of images, sounds, smells, haptics and tastes. In the beginning, all these sources of data were either generated by the physical environment or augmented by human influences. A simple example of this is the human guide or mentor who adds information and/or sensations which enhance and enrich the physical world.

Cave paintings (Figure 4) are an early example of augmented reality. The drawn images stimulate the senses to break the barriers of time and space for the viewer to bring a new experience and a modified perceived reality.

Figure 4: Ancient Cave Painting (Licensed under creative commons).

The evolution of mixed reality whether it be augmenting the physical world with images, sounds, smells, haptics and tastes or presenting a virtual environment experience augmented by real artefacts has been shaped by advances in technology.

The impact of communications technology on mixed reality

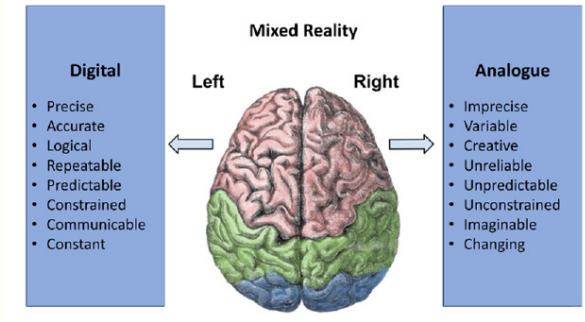

Figure 5: Mixed Reality and the Human Brain (Licenced under creative commons).

Digital Technologies represent a quantum change in the evolution of mixed reality. Figure 5 seeks to represent the differences between digital and analogue data. Our perception of reality is based on analogue sources of data from our 5 senses. We do not sense our world in a digital "Black or White, 1 or 0" way. Our perception of

reality relies on infinite variations in visual, auditory and sensory signals.

The digital age has not only revolutionized computational and "Newtonian" sciences by bringing unprecedented levels of precision, accuracy and power to the processing of and transfer of real-world data, it has also provided a way to capture and represent analogue data in a very precise and repeatable way. This has provided a way to capture sensor data, reproduce it accurately, store it indefinitely and share it electronically potentially to anywhere at anytime.

The digitization of sensory data such as audio and video is a critical component in what we now call virtual reality. Whilst it had been possible since the early 20th century to capture images and sounds in analogue format in the form of photos, film, records and tapes, these forms of sensory experiences were limited not only in quality but also in time and space. Recorded sounds, images and video recordings can augment our physical world and have done so in locations such as museums, theme parks and entertainment venues but digital technologies provided a quantum improvement in both quality and accessibility.

The first iteration of digital audio came as early as 1937 with the invention of Pulse Code Modulation (PCM) by a British Scientist called Alec Reeves [2]. This invention would come to revolutionise the telecommunications industry because of its potential to overcome the limitations of the copper cables used in telephone networks. It was until 1977 however that the first commercial digital audio recordings were released [3].

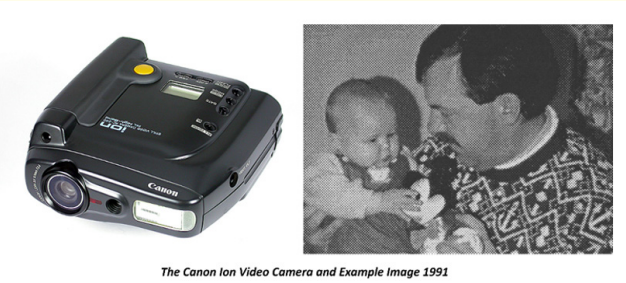

Figure 6: Forerunner of Digital Cameras (Licenced under Creative Commons).

The digitisation of images and video came much later and with all these developments in the human ability to capture, store and share sensory data in electronic format came opportunities to enhance and augment real world experiences. The Canon Ion camera [4] of the early 1990s shown in figure 6 was a forerunner of the digital cameras of today. It had the capability to convert visual data into electronic analogue data which was stored on a mini-disk inside the camera. The image quality was very poor by today's standards with a resolution of 320x200 pixels as shown by the example image, originally printed on an early HP laserjet mono printer in 1991.

The dawn of virtual reality

Virtual Reality can be regarded as an immersive experience through which we can lose awareness of our immediate physical environment and escape to an imaginary world. The entertainment sector has largely driven developments in virtual reality with many examples in theme parks where a combination of a whole range of sensory experiences aims to totally absorb us. Technologies which capture, store and share visual and auditory data are fundamental to many theme park rides and arcade games.

Virtual Reality as we know it today began in prototype form in the mid 1980s when a UK PhD student called Dr Jonathan Waldern demonstrated a system which created the illusion of 3D. He followed this with a prototype sit-down arcade machine in 1989 and set up a company called Virtuality [5].

Figure 7: 1990's Virtual Reality Ride (https://www.vrs.org.uk/dr-jonathan-walden-virtuality-new-reality-promise-two-decades-soon/).

Virtuality products were described as being 2 decades too soon for commercial success. The arcade "pods" shown above were powered by the Commodore Amiga 3000 which was the most powerful computer of the early 1990s. The arcade installations like Figure 7 had head tracking and 6 degrees of freedom. Like many disruptive technologies in their early stages, there were severe usability issues and a high level of cost, making them suitable only for entertainment installations with large numbers of visitors.

The prosumer phenomenon and mixed reality

From the dawn of what we recognize today as virtual reality experiences in the 1990s to the present day, one of the most significant developments has been the transition of digital devices which include computers and smartphones from being technologies capable of consuming mixed reality experiences to tools which enable consumers to produce and share digital content. This has been called the "Prosumer Revolution" [6]. One of the earliest articulations of the prosumer revolution was the so-called Web 2.0 which made it increasingly possible and affordable for individuals to create and maintain their own web sites along with video and audio content.

The facilitation of the prosumer revolution and democratization of the development of mixed reality experiences has been driven by the commercial potential of the cocktail of technologies which augment reality and create virtual reality experiences. These technologies include imaging, visualization, nano-technologies, haptic, mobile and wireless, all of which determine the richness and functionality of the experience.

Early examples of mixed reality

Excluding examples such as location specific audio guides of museums where Near Field Communication (NFC) devices are used to trigger digital recordings specific to a nearby exhibit, there have been technology-enabled augmented reality examples operating in a similar way to overlay the physical world with text, audio and images and triggered by GPS location data.

"Dockers' Dilemma" in 2008 was a project led by Celine Llewellyn-Jones [7]. Its aim was to augment the physical world of London's docklands with images and voice-overs that brought the sights and sounds of the 19th century to different physical locations using early smartphone technology. There have been many augmented reality projects using similar techniques that combine GPS location tracking with smartphone applications which augment the physical environment with sounds, images and videos.

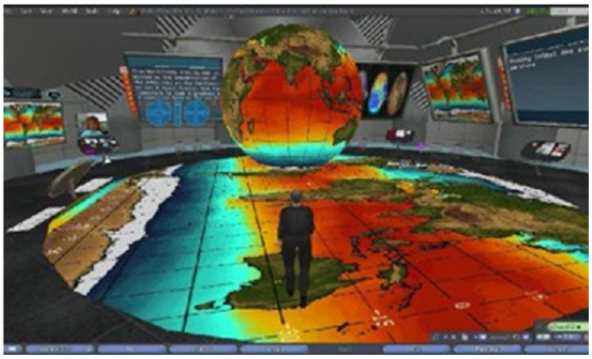

Figure 8: Datascape Data Visualisation (licensed by creative commons).

From 2007, a UK based company called Daden specialized in virtual environment technologies and collaborated with the Serious Games Institute (SGI) at Coventry University on a series of innovative Mixed Reality projects based around technology platforms such as Second Life. The platform was a good example of a prosumer technology that enabled anyone with a reasonably modern multimedia computer to build their own virtual world environments. Daden explored the potential of augmented virtuality by creating a virtual environment called "Datascape". Figure 8 shows an avatar in a Second Life Virtual Control Room. The map on the floor and the globe represent ocean temperatures around the world based on real world data. Around this 360 degree environment there are screens which show a series of live feeds taken from the internet, including live video.

The Datascape platform was able to be adapted to visualize real world data taken from a wide variety of sources, making it suitable for multiple applications which included, for example, real-time flight data and aircraft positions around the world in a to-tally immersive display. It made it possible for individuals from around the world to enter this virtual environment as avatars and share the experience on their computer screens within Second Life.

Another example of augmented virtuality which connected a virtual environment with a physical environment was developed

Figure 9: The Eolus Bridge Demonstrator (Licensed by creative commons).

as a result of a partnership between the Serious Games Institute and an entrepreneur called Oliver Goh who is now based in Lithuania. Their joint initiative was called SHASPA which was an abbreviation of "Intelligent Shared Spaces". It was based on the Second Life virtual world and sensor devices able to measure temperature and control heating and lighting. In the figure 9 demonstration example, a physical dolls house with heating and lighting was installed at the SGI. This dolls house was replicated in the virtual environment in such a way that its temperature and lighting status was mirrored in the virtual world. Switching lights on and off and altering the heating in the physical dolls house also did the same in its virtual copy.

Figure 10: The Nabaztag Demonstrator (Licensed under creative commons).

The final example of early mixed reality in the form of augmented virtuality involved the use of a device called a Nabaztag [9] (shown in Figure 10). This device took the shape of a rabbit and was linked to the internet using the SGI wifi network. The Nabaztag was able to rotate its ears and provide information through a speaker. Today its equivalent would be Amazon Alexis. In this use of augmented virtuality, a physical Nabaztag was placed in the office of the SGI Director with a virtual equivalent in the virtual world mirror. The virtual Nabaztag was programmed to recognize when an avatar entered the virtual office and activate the physical world Nabaztag to rotate its ears and alert the Director so that he could join the virtual visitor in the virtual office via his desktop computer.

The evolution of augmented reality

It may be deduced from the previous section that mixed reality in the shape of augmented virtuality developed faster than augmented reality in its ability to blend and connect physical and virtual environments. An explanation for this may be that the visualization and telecommunications technologies and platforms available in those early days made it easier to create virtual worlds that could be accessed from anywhere at any time whereas the only practical technology to augment reality was the mobile phone with GPS and NFC technologies necessary to sense its location in the physical world.

In the early years of the 21st century, the main application areas for augmented reality were seen as either tourism/museum/heritage based or for commercial uses for prompting consumers to visit nearby stores, usually in the form of messages triggered by proximity to a store.

Figure 11: Augmented Reality (licensed under creative commons).

An example of an augmented reality application for tourism is shown in figure 11. To make this type of augmented reality work effectively required smartphones with cameras, applications, wireless networks, processing power and artificial intelligence, all of which were not sufficiently evolved at the time. The smartphones and wireless networks available in most countries today would make these applications very practicable but the bigger questions of usability and customer acceptance present a barrier to their evolution. Consumers of today a looking for ease of use and instant access. Holding a mobile phone up, loading an application and then rotating the phone limits the convenience of augmented reality in this context.

Figure 12: Augmented Reality Glasses (licensed under creative commons).

The success of technology enabled augmented reality applications is being enhanced by the development of wearable glasses such as the one shown in figure 12. These devices are designed to be capable of seeing the real world clearly with a location based, context sensitive overlaid display. The limiting factors for the evolution of these types of devices have been the challenges involved in embedding the power and sophistication of the enabling technologies within such a small form factor.

Mixed reality in 2021

The evolution of mixed reality in the shape of augmented reality and augmented virtuality since these definitions were conceived in 1994 has been rapid and remarkable. This article has sought to propose that mixed reality as a concept is driven by a basic human need to break down the barriers of time and space and that the human brain and its 5 senses naturally augment reality and create virtual imaginary worlds.

The digital age has helped to build a bridge between a physical world based on Newtonian Physics and virtual worlds created in our imagination. The pace at which these developments have taken place has been determined by capabilities of a cocktail of enabling digital technologies and the emergence of the prosumer phenomenon.

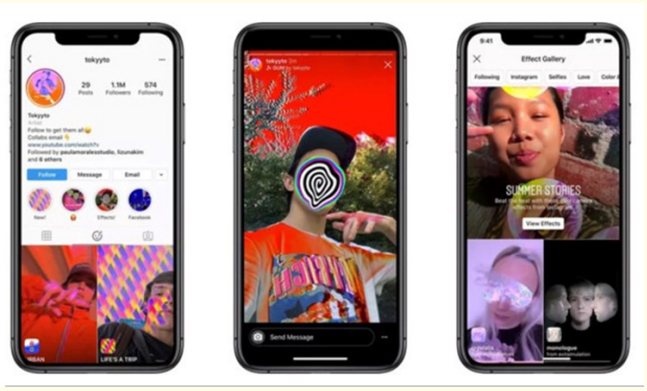

Figure 13: Smartphone augmented reality (Licensed under creative commons).

Today, with user-friendly tools such as Spark AR (Figure 13) and Facebook Portal, augmented reality is available to the masses via smartphones, home televisions and custom display devices at home. With video conferencing platforms like Zoom, it is very easy to augment reality with a customized background image or video.

Figure 14: In-car augmented reality projection (Licensed under creative commons).

Augmented reality using images projected onto a windscreen (Figure 14) of motor vehicles is now a practical possibility because of advances in the enabling technologies that can intelligently capture and process location and context sensitive information and display it as an overlay to what the driver sees in the real world.

Figure 15: 360 Degree Imaging (licensed under creative commons).

The development of consumer 360 degree cameras which can capture high fidelity panoramic images and videos such as the image of the Flying Scotsman steam locomotive at Kings Cross station shown in figure 15 makes the creation of virtual environments accessible to the mass market. Like the cave paintings of 10,000 years ago, images such as this capture a moment in time in unprecedented detail with an ability to share that virtually to a global audience on computers and smartphones.

Figure 16: Virtual Reality Headset and Controllers (Licensed under creative commons).

Virtual Reality Headsets and controllers like the ones shown in figure 16 make it possible to explore virtual worlds and experiences either as an individual or as a shared experience with other people. Many of the new headsets are wireless now that the processing power to render the images and videos can be embedded with the headset.

What is the mixed reality revolution?

This paper makes the argument that mixed reality is an essential existing component of human existence. Our brains use the 5 senses to perceive reality but they also have the capability to conceive virtual environments that exist in dreams and fantasies. Even what we understand as the real physical world exists virtually in the electrical signals within our brains. In this sense, mixed reality is not revolutionary in itself but rather evolves as we go through life and our memories are able to augment what we perceive as reality.

This paper argues that all advances in communications technology bring about step changes in what has been labelled augmented reality and virtual reality. The mixed reality revolution has been fuelled by technologies which are able to capture, store and share sensory information whether that be visual in the form of cave drawings or auditory in the form of recordings on phonographs or even haptic in the form of antique artefacts.

The real mixed reality revolution began when digital technologies made it possible to not only capture, store and share sensory data but also to make it accessible to a global audience. There has been a demand for mixed reality experiences that previously has been satisfied by creative people with passion and imagination but we have already entered a digital age where the enabling consumer technologies not only bring access to augmented reality experiences and virtual environments but also provide the tools for citizens to create, store and share their own augmented reality and virtual reality creations with a global audience.

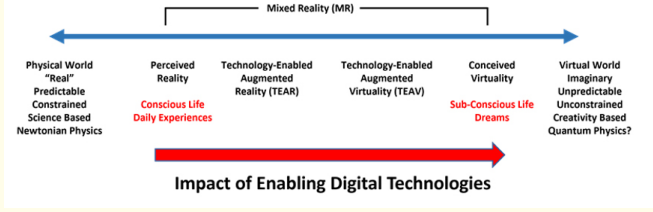

Figure 17: New Mixed Reality Continuum (Licensed under creative commons).

The impact of enabling digital technologies that not only capture, store and share sensory data but make creative tools widely available to a global market to democratize mixed reality is illustrated in figure 17. Digital enabling technologies are driving us towards a world in which reality and virtuality become blended and what we perceive as reality will become a hybrid of what physically exists and what is a virtual creation. This blending of real and virtual worlds has been described as the metaverse.

Mixed reality revolution opportunities

The mixed reality revolution and the disruptive nature of enabling digital technologies is arguably creating the most profound and exponential changes to human life the world has ever seen in the whole of history. The combination of enabling digital technologies and the demand from consumers to be able to create their own augmentations of reality (the prosumer phenomenon) means that every imaginable human activity and status will be impacted.

The opportunities created by the mixed reality revolution will bring new levels of functionality and empowerment across all sectors of society. Here are just a couple of examples.

Figure 18: Virtual Reality in Medical Education (Licensed under creative commons).

One of the most important opportunities afforded by mixed reality is in the area of health and medicine where mixed reality can be applied across the whole sector from medical education (Figure 18) through diagnostics to treatment to therapeutics, rehabilitation and remote care. Wearable and embedded medical devices which track our vital signs in real time can generate data which can be visualized in mixed reality either as augmented reality or augmented virtuality. These changes are already taking place and agencies like the USA Federal Drugs Agency (FDA) are classifying virtual reality therapeutic devices and applications as medical devices.

Figure 19: Virtual Reality Life Experiences Licensed under creative commons).

Developments in consumer panoramic cameras capturing real world events and life memories in virtual reality makes it possible to re-experience special people and events. Figure 19 is an example of mixed reality at the augmented virtuality end of the spectrum. The old gentleman sat in the chair is part of a "living memories" experience which can be visited online via computer or smartphone or virtual reality headset. The gentleman is now deceased but his family, through mixed reality, is able to virtually sit in his room and see and hear him sharing his memories augmented by animated portraits of his family.

Other positive opportunities enabled by the mixed reality revolution include :-

- The ability to monitor and manage the devices in your home remotely providing better security and energy management
- Remote learning capabilities enhanced by mixed reality experiences and visualisations that can take place in a virtual space augmented by real world elements
- Virtual meetings with telepresence capabilities which give the experience of being in the same room
- Richer virtual tourism applications which not only allow people to visit lo-cations and experience the sights and sounds but also provide a virtual guide
- Real Estate applications using either real 360 degree images and video or synthetic computer graphics images to allow buyers to have a guided tour around properties.

The range of opportunities already technically possible is only limited by human imagination.

Mixed reality revolution challenges

Like any revolution bringing disruptive change to the status quo, there will be challenges which are likely to be severe given the potential impact on daily life which all of us as consumers are helping to drive. The major challenges fall into 2 main categories:-

Technical challenges

The mixed reality revolution is founded on a cocktail of digital technologies which enable the digital capture, storage and sharing of sensor data. The sensor technologies that make this possible primarily focus on visual and audio data which are the two most important human senses that are used to perceive the real world. There are technologies which have been and are being developed to digitize smells, tastes and touch but these are very embryonic although haptic technologies are the most advanced of these human senses. Since sight and hearing are the most important and easy to digitize, we are already at a stage where what can be seen and heard through technologies such as virtual reality headsets is becoming indistinguishable from perceived reality.

Another technical challenge is the form factor of devices used to experience mixed reality. Currently, virtual reality headsets are restricted by their size and usability. They require users to essentially physically immerse themselves in a headset which shuts the user off from the physical world around them are requires the use of hand-held controllers to navigate around and interact with the virtual environment. This is a current limitation of what has been described as augmented virtuality. The technology itself is not ambient or transparent to the real world and therefore creates a barrier between real and virtual.

In the case of augmented reality where the AR glasses being developed and the example of the motoring application both are ambient, these devices provide a genuine overlay to what the wearer experiences in the real world and are therefore easier to wear and use. Because of their size and wireless nature, the technical challenge is how to incorporate all the enabling technologies in such a small device and how to power the device. This is in addition to the technical challenges of creating a transparent display lens that can also use augmented data from a relevant source.

If these challenges can be overcome and provided the real world is embedded with sensor technologies that can interact with these wearable devices, it is possible that we shall see AR glasses able to both augment reality and switch to a totally immersive virtual world augmented by real world objects.

Societal and psychological challenges

Whilst the experience of mixed reality can be exciting and attractive with many applications that provide positive benefits to both users and society, like many other digital technologies, it challenges established practices and hierarchies. When mixed reality devices with embedded artificial intelligence are used to deliver services that compete with hu-man knowledge professionals, there will be an understandable resistance.

The mixed reality revolution is not unique in this regard as these disruptions are already being observed in many sectors as a result of other digital technologies. A good relevant example in the medical sector is the processing of MRI scan data by artificial intelligence proving in many cases to be better than trained radiologists. In sectors like medicine and health where there are strict protocols for new treatments, the use of mixed reality for digital therapeutics and rehabilitation may take time to be accepted by the sector.

From a psychological perspective mixed reality devices that are worn on the head and address sight and hearing are still not sufficiently "transparent and ambient" to gain full user acceptance. This does not apply so much to augmented and virtual reality applications experienced on smartphones, computer screens/laptops and TV screens. This is likely to be because the devices themselves are very familiar and usable for many different applications.

Future developments

The Metaverse is a rapidly developing phenomenon, whose development has been accelerated by the COVID-19 pandemic which has restricted physical contact and also limited physical travel. Although the world shows signs of recovering from these restrictions, other factors such as global warming, climate change and military conflicts may mean that humans will need to use virtual communications technologies for many types of activity in the future, including for meetings, trade, socialisation and entertainment.

The barriers in technology maturity and usability that currently exist such as VR and AR headset form factors and user experience, are likely to be addressed once nanotechnology and battery power limitations are overcome. Future studies could explore the evolution of mixed reality and the key factors which influence both types of mixed reality applications and the devices we use to access them.

Summary and Conclusion

This paper has sought to put the mixed reality revolution into context by exploring the human aspects of mixed reality. Human beings already exist in a form of mixed reality because of the way that our brains process the sensory information that perceives reality but also conceives virtuality in our creative processes.

The two most important factors that have created a mixed reality revolution, in the author's opinion are digital technologies that capture, store and share sensory data (primarily visual and audio) and the prosumer phenomenon which drives consumers to demand technologies that not only make mixed reality experiences affordable and accessible on demand but also allow consumers to create, store and share their own mixed reality experiences.

We have come a long way since the terms augmented reality and augmented virtuality were coined in 1994 but today we are on the threshold of the metaverse in which the boundaries between reality and virtuality are broken down and we learn to live in a hybrid world that blends both worlds together.

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