Wikipedia

Augmented reality

Virtual Fixtures – first AR system, U.S. Air Force, Wright-Patterson Air Force Base (1992)

Augmented reality (**AR**) is an interactive experience of a real-world environment where the objects that reside in the real-world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory.[1][2] The overlaid sensory information can be constructive (i.e. additive to the natural environment), or destructive (i.e. masking of the natural environment).[3] This experience is seamlessly interwoven with the physical world such that it is perceived as an immersive aspect of the real environment.[3] In this way, augmented reality alters one's ongoing perception of a real-world environment, whereas virtual reality completely replaces the user's real-world environment with a simulated one.[4][5] Augmented reality is related to two largely synonymous terms: mixed reality and computer-mediated reality.

The primary value of augmented reality is the manner in which components of the digital world blend into a person's perception of the real world, not as a simple display of data, but through the integration of immersive sensations, which are perceived as natural parts of an environment. The earliest functional AR systems that provided immersive mixed reality experiences for users were invented in the early 1990s, starting with the Virtual Fixtures system developed at the U.S. Air Force's Armstrong Laboratory in 1992.[3][6][7] Commercial augmented reality experiences were first introduced in entertainment and gaming businesses. Subsequently, augmented reality applications have spanned commercial industries such as education, communications, medicine, and entertainment. In education, content may be accessed by scanning or viewing an image with a mobile device or by using markerless AR techniques.[8][9] An example relevant to the construction industry is an AR helmet for construction workers which displays information about construction sites.

Augmented reality is used to enhance natural environments or situations and offer perceptually enriched experiences. With the help of advanced AR technologies (e.g. adding computer vision, incorporating AR cameras into smartphone applications and object recognition) the information about the surrounding real world of the user becomes interactive and digitally manipulated. Information about the environment and its objects is overlaid on the real world. This information can be virtual[10][11][12][13] or real, e.g. seeing other real sensed or measured information such as electromagnetic radio waves overlaid in exact alignment with where they actually are in space.[14][15][16] Augmented reality also has a lot of potential in the gathering and sharing of tacit knowledge. Augmentation techniques are typically performed in real time and in semantic contexts with environmental elements. Immersive perceptual information is sometimes combined with supplemental information like scores over a live video feed of a sporting event. This combines the benefits of both augmented reality technology and heads up display technology (HUD).

Contents

The difference between Virtual Reality & Augmented Reality

In Virtual Reality (VR), the users' perception of reality is completely based on virtual information. In Augmented Reality (AR) the user is provided with additional computer generated information that enhances their perception of reality.[17][18] For example, in architecture, VR can be used to create a walk-though simulation of the inside of a new building; and AR can be used to show a building's structures and systems super-imposed on a real-life view.

Technology

Hardware

Hardware components for augmented reality are: a processor, display, sensors and input devices. Modern mobile computing devices like smartphones and tablet computers contain these elements, which often include a camera and Microelectromechanical systems (MEMS) sensors such as an accelerometer, GPS, and solid state compass, making them suitable AR platforms.[19] There are two technologies used in augmented reality: diffractive waveguides and reflective waveguides.

Display

Various technologies are used in augmented reality rendering, including optical projection systems, monitors, handheld devices, and display systems, which are worn on the human body.

Man wearing smartglasses

A head-mounted display (HMD) is a display device worn on the forehead, such as a harness or helmet-mounted. HMDs place images of both the physical world and virtual objects over the user's field of view. Modern HMDs often employ sensors for six degrees of freedom monitoring that allow the system to align virtual information to the physical world and adjust accordingly with the user's head movements.[20][21][22] HMDs can provide VR users with mobile and collaborative experiences.[23] Specific providers, such as uSens and Gestigon, include gesture controls for full virtual immersion.[24][25]

In January 2015, Meta launched a project led by Horizons Ventures, Tim Draper, Alexis Ohanian, BOE Optoelectronics and Garry Tan.[26][27][28] On 17 February 2016, Meta announced their second-generation product at TED, Meta 2. The Meta 2 head-mounted display headset uses a sensory array for hand interactions and positional tracking, visual field view of 90 degrees (diagonal), and resolution display of 2560 x 1440 (20 pixels per degree), which is considered the largest field of view (FOV) currently available.[29][30][31][32]

Eyeglasses

AR displays can be rendered on devices resembling eyeglasses. Versions include eyewear that employs cameras to intercept the real world view and re-display its augmented view through the eyepieces[33] and devices in which the AR imagery is projected through or reflected off the surfaces of the eyewear lens pieces.[34][35][36]

HUD

Headset computer

A head-up display (HUD) is a transparent display that presents data without requiring users to look away from their usual viewpoints. A precursor technology to augmented reality, heads-up displays were first developed for pilots in the 1950s, projecting simple flight data into their line of sight, thereby enabling them to keep their "heads up" and not look down at the instruments. Near-eye augmented reality devices can be used as portable head-up displays as they can show data, information, and images while the user views the real world. Many definitions of augmented reality only define it as overlaying the information.[37][38] This is basically what a head-up display does; however, practically speaking, augmented reality is expected to include registration and tracking between the superimposed perceptions, sensations, information, data, and images and some portion of the real world.[39]

Contact lenses

Contact lenses that display AR imaging are in development. These bionic contact lenses might contain the elements for display embedded into the lens including integrated circuitry, LEDs and an antenna for wireless communication. The first contact lens display was reported in 1999,[40] then 11 years later in 2010-2011.[41][42][43][44] Another version of contact lenses, in development for the U.S. military, is designed to function with AR spectacles, allowing soldiers to focus on close-to-the-eye AR images on the spectacles and distant real world objects at the same time.[45][46]

The futuristic short film *Sight*[47] features contact lens-like augmented reality devices.[48][49]

Many scientists have been working on contact lenses capable of different technological feats. A patent filed by Samsung describes an AR contact lens, that, when finished, will include a built-in camera on the lens itself.[50] The design is intended to control its interface by blinking an eye. It is also intended to be linked with the user's smartphone to review footage, and control it separately. When successful, the lens would feature a camera, or sensor inside of it. It is said that it could be anything from a light sensor, to a temperature sensor.

In Augmented Reality, the distinction is made between two distinct modes of tracking, known as *marker* and *markerless*. Markers are visual cues which trigger the display of the virtual information.[51] A piece of paper with some distinct geometries can be used. The camera recognizes the geometries by identifying specific points in the drawing. Markerless tracking, also called instant tracking, does not use markers. Instead, the user positions the object in the camera view preferably in a horizontal plane. It uses sensors in mobile devices to accurately detect the real-world environment, such as the locations of walls and points of intersection.[52]

Virtual retinal display

A virtual retinal display (VRD) is a personal display device under development at the University of Washington's Human Interface Technology Laboratory under Dr. Thomas A. Furness III.[53] With this technology, a display is scanned directly onto the retina of a viewer's eye. This results in bright images with high resolution and high contrast. The viewer sees what appears to be a conventional display floating in space.[54]

Several of tests were done to analyze the safety of the VRD.[53] In one test, patients with partial loss of vision—having either macular degeneration (a disease that degenerates the retina) or keratoconus—were selected to view images using the technology. In the macular degeneration group, five out of eight subjects preferred the VRD images to the cathode-ray tube (CRT) or paper images and thought they were better and brighter and were able to see equal or better resolution levels. The Keratoconus patients could all resolve smaller lines in several line tests using the VDR as opposed to their own correction. They also found the VDR images to be easier to view and sharper. As a result of these several tests, virtual retinal display is considered safe technology.

Virtual retinal display creates images that can be seen in ambient daylight and ambient room light. The VRD is considered a preferred candidate to use in a surgical display due to its combination of high resolution and high contrast and brightness. Additional tests show high potential for VRD to be used as a display technology for patients that have low vision.

EyeTap

The EyeTap (also known as Generation-2 Glass[55]) captures rays of light that would otherwise pass through the center of the lens of the wearer's eye, and substitutes synthetic computer-controlled light for each ray of real light.

The Generation-4 Glass[55] (Laser EyeTap) is similar to the VRD (i.e. it uses a computer-controlled laser light source) except that it also has infinite depth of focus and causes the eye itself to, in effect, function as both a camera and a display by way of exact alignment with the eye and resynthesis (in laser light) of rays of light entering the eye.[56]

Handheld

A Handheld display employs a small display that fits in a user's hand. All handheld AR solutions to date opt for video see-through. Initially handheld AR employed fiducial markers,[57] and later GPS units and MEMS sensors such as digital compasses and six degrees of freedom accelerometer–gyroscope. Today Simultaneous localization and mapping (SLAM) markerless trackers such as PTAM (parallel tracking and mapping) are starting to come into use. Handheld display AR promises to be the first commercial success for AR technologies. The two main advantages of handheld AR are the portable nature of handheld devices and the ubiquitous nature of camera phones. The disadvantages are the physical constraints of the user having to hold the handheld device out in front of them at all times, as well as the distorting effect of classically wide-angled mobile phone cameras when compared to the real world as viewed through the eye.[58]

Games such as *Pokémon Go* and *Ingress* utilize an Image Linked Map (ILM) interface, where approved geotagged locations appear on a stylized map for the user to interact with.[59]

Spatial

Spatial augmented reality (SAR) augments real-world objects and scenes, without the use of special displays such as monitors, head-mounted displays or hand-held devices. SAR makes use of digital projectors to display graphical information onto physical objects. The key difference in SAR is that the display is separated from the users of the system. Since the displays are not associated with each user, SAR scales naturally up to groups of users, allowing for collocated collaboration between users.

Examples include shader lamps, mobile projectors, virtual tables, and smart projectors. Shader lamps mimic and augment reality by projecting imagery onto neutral objects. This provides the opportunity to enhance the object's appearance with materials of a simple unit—a projector, camera, and sensor.

Other applications include table and wall projections. One innovation, the Extended Virtual Table, separates the virtual from the real by including beam-splitter mirrors attached to the ceiling at an adjustable angle.[60] Virtual showcases, which employ beam splitter mirrors together with multiple graphics displays, provide an interactive means of simultaneously engaging with the virtual and the real. Many more implementations and configurations make spatial augmented reality display an increasingly attractive interactive alternative.

A SAR system can display on any number of surfaces in an indoor setting at once. SAR supports both a graphical visualization and passive haptic sensation for the end users. Users are able to touch physical objects in a process that provides passive haptic sensation.[13][61][62][63]

Tracking

Modern mobile augmented-reality systems use one or more of the following motion tracking technologies: digital cameras and/or other optical sensors, accelerometers, GPS, gyroscopes, solid state compasses, Radio-frequency identification (RFID). These technologies offer varying levels of accuracy and precision. The most important is the position and orientation of the user's head. Tracking the user's hand(s) or a handheld input device can provide a 6DOF interaction technique.[64][65]

Networking

Mobile augmented reality applications are gaining popularity because of the wide adoption of mobile and especially wearable devices. However, they often rely on computationally intensive computer vision algorithms with extreme latency requirements. To compensate for the lack of computing power, offloading data processing to a distant machine is often desired. Computation offloading introduces new constraints in applications, especially in terms of latency and bandwidth. Although there are a plethora of real-time multimedia transport protocols, there is a need for support from network infrastructure as well.[66]

Input devices

Techniques include speech recognition systems that translate a user's spoken words into computer instructions, and gesture recognition systems that interpret a user's body movements by visual detection or from sensors embedded in a peripheral device such as a wand, stylus, pointer, glove or other body wear.[67][68][69][70] Products which are trying to serve as a controller of AR headsets include Wave by Seebright Inc. and Nimble by Intugine Technologies.

Computer

The computer analyzes the sensed visual and other data to synthesize and position augmentations. Computers are responsible for the graphics that go with augmented reality. Augmented reality uses a computer-generated image which has a striking effect on the way the real world is shown. With the improvement of technology and computers, augmented reality is going to lead to a drastic change on ones perspective of the real world.[71] According to *Time*, in about 15–20 years it is predicted that augmented reality and virtual reality are going to become the primary use for computer interactions.[72] Computers are improving at a very fast rate, leading to new ways to improve other technology. The more that computers progress, augmented reality will become more flexible and more common in society. Computers are the core of augmented reality. [73] The computer receives data from the sensors which determine the relative position of an objects' surface. This translates to an input to the computer which then outputs to the users by adding something that would otherwise not be there. The computer comprises memory and a processor.[74] The computer takes the scanned environment then generates images or a video and puts it on the receiver for the observer to see. The fixed marks on an object's surface are stored in the memory of a computer. The computer also withdraws from its memory to present images realistically to the onlooker. The best example of this is of the Pepsi Max AR Bus Shelter.[75]

Software and algorithms

A key measure of AR systems is how realistically they integrate augmentations with the real world. The software must derive real world coordinates, independent of camera, and camera images. That process is called image registration, and uses different methods of computer vision, mostly related to video tracking.[76][77] Many computer vision methods of augmented reality are inherited from visual odometry.

Usually those methods consist of two parts. The first stage is to detect interest points, fiducial markers or optical flow in the camera images. This step can use feature detection methods like corner detection, blob detection, edge detection or thresholding, and other image processing methods.[78][79] The second stage restores a real world coordinate system from the data obtained in the first stage. Some methods assume objects with known geometry (or fiducial markers) are present in the scene. In some of those cases the scene 3D structure should be calculated beforehand. If part of the scene is unknown simultaneous localization and mapping (SLAM) can map relative positions. If no information about scene geometry is available, structure from motion methods like bundle adjustment are used. Mathematical methods used in the second stage include: projective (epipolar) geometry, geometric algebra, rotation representation with exponential map, kalman and particle filters, nonlinear optimization, robust statistics.

Augmented Reality Markup Language (ARML) is a data standard developed within the Open Geospatial Consortium (OGC),[80] which consists of Extensible Markup Language (XML) grammar to describe the location and appearance of virtual objects in the scene, as well as ECMAScript bindings to allow dynamic access to properties of virtual objects.

To enable rapid development of augmented reality applications, some software development kits (SDKs) have emerged.[81][82]

Recent research compared the functionalities of augmented reality tools with potential for education.[83]

Development

The implementation of augmented reality in consumer products requires considering the design of the applications and the related constraints of the technology platform. Since AR systems rely heavily on the immersion of the user and the interaction between the user and the system, design can facilitate the adoption of virtuality. For most augmented reality systems, a similar design guideline can be followed. The following lists some considerations for designing augmented reality applications:

Environmental/context design

Context Design focuses on the end-user's physical surrounding, spatial space, and accessibility that may play a role when using the AR system. Designers should be aware of the possible physical scenarios the end-user may be in such as:

- Public, in which the users use their whole body to interact with the software
- Personal, in which the user uses a smartphone in a public space
- Intimate, in which the user is sitting with a desktop and is not really moving
- Private, in which the user has on a wearable.[84]

By evaluating each physical scenario, potential safety hazards can be avoided and changes can be made to greater improve the end-user's immersion. UX designers will have to define user journeys for the relevant physical scenarios and define how the interface reacts to each.

Especially in AR systems, it is vital to also consider the spatial and surrounding elements that change the effectiveness of the AR technology. Environmental elements such as lighting and sound can prevent the AR device sensor from detecting necessary data and ruin the immersion of the end-user.[85]

Another aspect of context design involves the design of the system's functionality and its ability to accommodate user preferences.[86][87] While accessibility tools are common in basic application design, some consideration should be made when designing time-limited prompts (to prevent unintentional operations), audio cues and overall engagement time. It is important to note that in some situations, the application's functionality may hinder the user's ability. For example, applications that is used for driving should reduce the amount of user interaction and use audio cues instead.

Interaction design

Interaction design in augmented reality technology centers on the user's engagement with the end product to improve the overall user experience and enjoyment. The purpose of interaction design is to avoid alienating or confusing the user by organizing the information presented. Since user interaction relies on the user's input, designers must make system controls easier to understand and accessible. A common technique to improve usability for augmented reality applications is by discovering the frequently accessed areas in the device's touch display and design the application to match those areas of control.[88] It is also important to structure the user journey maps and the flow of information presented which reduce the system's overall cognitive load and greatly improves the learning curve of the application.[89]

In interaction design, it is important for developers to utilize augmented reality technology that complement the system's function or purpose.[90] For instance, the utilization of exciting AR filters and the design of the unique sharing platform in Snapchat enables users to better the user's social interactions. In other applications that require users to understand the focus and intent, designers can employ a reticle or raycast from the device.[86] Moreover, augmented reality developers may find it appropriate to have digital elements scale or react to the direction of the camera and the context of objects that can are detected.[85]

Augmented reality technology allows to utilize the introduction of 3D space. This means that a user can potentially access multiple copies of 2D interfaces within a single AR application.[85]

Visual design

In general, visual design is the appearance of the developing application that engages the user. To improve the graphic interface elements and user interaction, developers may use visual cues to inform the user what elements of UI are designed to interact with and how to interact with them. Since navigating in an AR application may appear difficult and seem frustrating, visual cue design can make interactions seem more natural.[84]

In some augmented reality applications that use a 2D device as an interactive surface, the 2D control environment does not translate well in 3D space making users hesitant to explore their surroundings. To solve this issue, designers should apply visual cues to assist and encourage users to explore their surroundings.

It is important to note the two main objects in AR when developing VR applications: 3D volumetric objects that are manipulated and realistically interact with light and shadow; and animated media imagery such as images and videos which are mostly traditional 2D media rendered in a new context for augmented reality.[84] When virtual objects are projected onto a real environment, it is challenging for augmented reality application designers to ensure a perfectly seamless integration relative to the real-world environment, especially with 2D objects. As such, designers can add weight to objects, use depths maps, and choose different material properties that highlight the object's presence in the real world. Another visual design that can be applied is using different lighting techniques or casting shadows to improve overall depth judgment. For instance, a common lighting technique is simply placing a light source overhead at the 12 o'clock position, to create shadows on virtual objects.[84]

Possible applications

Augmented reality has been explored for many applications, from gaming and entertainment to medicine, education and business. Example application areas described below include archaeology, architecture, commerce and education. Some of the earliest cited examples include augmented reality used to support surgery by providing virtual overlays to guide medical practitioners, to AR content for astronomy and welding.[7][91]

Recent research compared the functionalities of augmented reality tools with potential for education.[83]

Archaeology

AR has been used to aid archaeological research. By augmenting archaeological features onto the modern landscape, AR allows archaeologists to formulate possible site configurations from extant structures.[92] Computer generated models of ruins, buildings, landscapes or even ancient people have been recycled into early archaeological AR applications.[93][94][95] For example, implementing a system like, VITA (Visual Interaction Tool for Archaeology) will allow users to imagine and investigate instant excavation results without leaving their home. Each user can collaborate by mutually "navigating, searching, and viewing data". Hrvoje Benko, a researcher in the computer science department at Columbia University, points out that these particular systems and others like them can provide "3D panoramic images and 3D models of the site itself at different excavation stages" all the while organizing much of the data in a collaborative way that is easy to use. Collaborative AR systems supply multimodal interactions that combine the real world with virtual images of both environments.[96] AR has also been recently adopted in the underwater archaeology field to efficiently support and facilitate the manipulation of archaeological artifacts.[97]

Architecture

AR can aid in visualizing building projects. Computer-generated images of a structure can be superimposed onto a real-life local view of a property before the physical building is constructed there; this was demonstrated publicly by Trimble Navigation in 2004. AR can also be employed within an architect's workspace, rendering animated 3D visualizations of their 2D drawings. Architecture sight-seeing can be enhanced with AR applications, allowing users viewing a building's exterior to virtually see through its walls, viewing its interior objects and layout.[98][99][100]

With continual improvements to GPS accuracy, businesses are able to use augmented reality to visualize georeferenced models of construction sites, underground structures, cables and pipes using mobile devices.[101] Augmented reality is applied to present new projects, to solve on-site construction challenges, and to enhance promotional materials.[102] Examples include the Daqri Smart Helmet, an Android-powered hard hat used to create augmented reality for the industrial worker, including visual instructions, real-time alerts, and 3D mapping.

Following the Christchurch earthquake, the University of Canterbury released CityViewAR,[103] which enabled city planners and engineers to visualize buildings that had been destroyed.[104] This not only provided planners with tools to reference the previous cityscape, but it also served as a reminder of the magnitude of the resulting devastation, as entire buildings had been demolished.

STEM Education

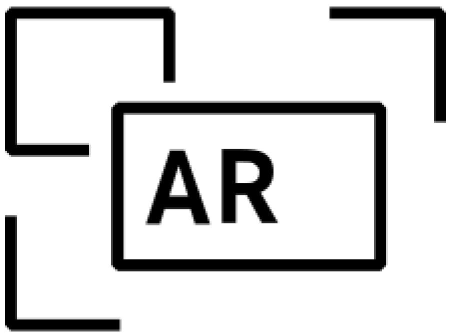
In educational settings, AR has been used to complement a standard curriculum. Text, graphics, video, and audio may be superimposed into a student's real-time environment. Textbooks, flashcards and other educational reading material may contain embedded "markers" or triggers that, when scanned by an AR device, produced supplementary information to the student rendered in a multimedia format.[105][106][107] 2015's *Virtual, Augmented and Mixed Reality: 7th International Conference* mentioned Google Glass as an example of augmented reality that can replace the physical classroom.[108]

As AR evolves, students can participate interactively and interact with knowledge more authentically. Instead of remaining passive recipients, students can become active learners, able to interact with their learning environment. Computer-generated simulations of historical events allow students to explore and learning details of each significant area of the event site.[109]

In higher education, Construct3D, a Studierstube system, allows students to learn mechanical engineering concepts, math or geometry.[110] Chemistry AR apps allow students to visualize and interact with the spatial structure of a molecule using a marker object held in the hand.[111] Others have used HP Reveal, a free app, to create AR notecards for studying organic chemistry mechanisms or to create virtual demonstrations of how to use laboratory instrumentation.[112] Anatomy students can visualize different systems of the human body in three dimensions.[113]

Commerce

AR is used to integrate print and video marketing. Printed marketing material can be designed with certain "trigger" images that, when scanned by an AR-enabled device using image recognition, activate a video version of the promotional material. A major difference between augmented reality and straightforward image recognition is that one can overlay multiple media at the same time in the view screen, such as social media share buttons, the in-page video even audio and 3D objects. Traditional print-only publications are using augmented reality to connect different types of media.[114][115][116][117][118]



The AR-Icon can be used as a marker on print as well as on online media. It signals the viewer that digital content is behind it. The content can be viewed with a smartphone or tablet

AR can enhance product previews such as allowing a customer to view what's inside a product's packaging without opening it.[119] AR can also be used as an aid in selecting products from a catalog or through a kiosk. Scanned images of products can activate views of additional content such as customization options and additional images of the product in its use.[120]

By 2010, virtual dressing rooms had been developed for e-commerce.[121]

In 2012, a mint used AR techniques to market a commemorative coin for Aruba. The coin itself was used as an AR trigger, and when held in front of an AR-enabled device it revealed additional objects and layers of information that were not visible without the device.[122][123]

In 2015, the Bulgarian startup iGreet developed its own AR technology and used it to make the first premade "live" greeting card. A traditional paper card was augmented with digital content which was revealed using the iGreet app.[124][125]

In 2018, Apple announced USDZ AR file support for iPhones and iPads with iOS12. Apple has created an AR QuickLook Gallery that allows masses to experience augmented reality on their own Apple device.[126]

In 2018, Shopify, the Canadian e-commerce company, announced ARkit2 integration. Their merchants are able to use the tools to upload 3D models of their products. Users will be able to tap on the goods inside Safari to view in their real-world environments.[127]

In 2018, Twinkl released a free AR classroom application. Pupils can see how York looked over 1,900 years ago.[128] Twinkl launched the first ever multi-player AR game, *Little Red*[129] and has over 100 free AR educational models.[130]

Augmented reality is becoming more frequently used for online advertising. Retailers offer the ability to upload a picture on their website and "try on" various clothes which are overlaid on the picture. Even further, companies such as Bodymetrics install dressing booths in department stores that offer full-body scanning. These booths render a 3-D model of the user, allowing the consumers to view different outfits on themselves without the need of physically changing clothes.[131] For example, JC Penney and Bloomingdale's use "virtual dressing rooms" that allow customers to see themselves in clothes without trying them on.[132] Another store that uses AR to market clothing to its customers is Neiman Marcus.[133] Neiman Marcus offers consumers the ability to see their outfits in a 360 degree view with their "memory mirror".[133] Makeup stores like L'Oreal, Sephora, Charlotte Tilbury, and Rimmel also have apps that utilize AR.[134] These apps allow consumers to see how the makeup will look on them.[134] According to Greg Jones, director of AR and VR at Google, augmented reality is going to "reconnect physical and digital retail".[134]

AR technology is also used by furniture retailers such as IKEA, Houzz, and Wayfair.[134][132] These retailers offer apps that allow consumers to view their products in their home prior to purchasing anything.[134] In 2017, Ikea announced the Ikea Place app. It contains a catalogue of over 2,000 products—nearly the company's full collection of sofas, armchairs, coffee tables, and storage units which one can place anywhere in a room with their phone.[135] The app made it possible to have 3D and true-to-scale models of furniture in the customer's living space. IKEA realized that their customers are not shopping in stores as often or making direct purchases anymore.[136][137]

Literature

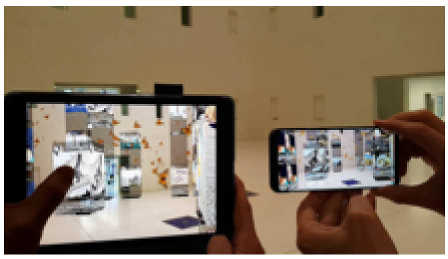
The first description of AR as it is known today was in *Virtual Light*, the 1994 novel by William Gibson. In 2011, AR was blended with poetry by ni ka from Sekai Camera in Tokyo, Japan. The prose of these AR poems come from Paul Celan, *Die Niemandsrose*, expressing the aftermath of the 2011 Tōhoku earthquake and tsunami.[138][139][140]

An example of an AR code containing a QR code

Visual art

AR applied in the visual arts allows objects or places to trigger artistic multidimensional experiences and interpretations of reality.

Augmented reality can aid in the progression of visual art in museums by allowing museum visitors to view artwork in galleries in a multidimensional way through their phone screens. The Museum of Modern Art in New York has created an exhibit in their art museum showcasing AR features that viewers can see using an app on their smartphone.[142] The museum has developed their personal app, called MoMAR Gallery, that museum guests can download and use in the Augmented Reality specialized gallery in order to view the museum's paintings in a different way.[143] This allows individuals to see hidden aspects and information about the paintings, and to be able to have an interactive technological experience with artwork as well.


10.000 Moving Cities, Marc Lee, Augmented Reality Multiplayer Game, Art Installation[141]

AR technology was also used in two of the public art pieces in the 2019 Desert X exhibition.[144]

AR technology aided the development of eye tracking technology to translate a disabled person's eye movements into drawings on a screen.[145]

Remote collaboration

Primary school children learn easily from interactive experiences. As an example, astronomical constellations and the movements of objects in the solar system were oriented in 3D and overlaid in the direction the device was held, and expanded with supplemental video information. Paper-based science book illustrations could seem to come alive as video without requiring the child to navigate to web-based materials.

In 2013, a project was launched on Kickstarter to teach about electronics with an educational toy that allowed children to scan their circuit with an iPad and see the electric current flowing around.[146] While some educational apps were available for AR by 2016, it was not broadly used. Apps that leverage augmented reality to aid learning included SkyView for studying astronomy,[147] AR Circuits for building simple electric circuits,[148] and SketchAr for drawing.[149]

AR would also be a way for parents and teachers to achieve their goals for modern education, which might include providing more individualized and flexible learning, making closer connections between what is taught at school and the real world, and helping students to become more engaged in their own learning.

Recent research compared the functionalities of augmented reality tools with potential for education.[83]

Emergency management/search and rescue

Augmented reality systems are used in public safety situations, from super storms to suspects at large.

As early as 2009, two articles from *Emergency Management* magazine discussed the power of this technology for emergency management. The first was "Augmented Reality--Emerging Technology for Emergency Management" by Gerald Baron.[150] According to Adam Crowe: "Technologies like augmented reality (ex: Google Glass) and the growing expectation of the public will continue to force professional emergency managers to radically shift when, where, and how technology is deployed before, during, and after disasters."[151]

Another early example was a search aircraft looking for a lost hiker in rugged mountain terrain. Augmented reality systems provided aerial camera operators with a geographic awareness of forest road names and locations blended with the camera video. The camera operator was better able to search for the hiker knowing the geographic context of the camera image. Once located, the operator could more efficiently direct rescuers to the hiker's location because the geographic position and reference landmarks were clearly labeled.[152]

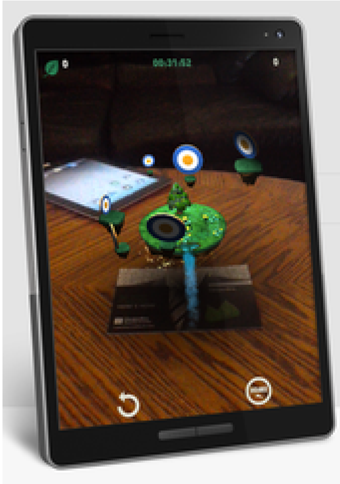
Social interaction

AR can be used to facilitate social interaction. An augmented reality social network framework called Talk2Me enables people to disseminate information and view others' advertised information in an augmented reality way. The timely and dynamic information sharing and viewing functionalities of Talk2Me help initiate conversations and make friends for users with people in physical proximity.[153]

Augmented reality also gives users the ability to practice different forms of social interactions with other people in a safe, risk-free environment. Hannes Kauffman, Associate Professor for Virtual Reality at TU Vienna, says: "In collaborative Augmented Reality multiple users may access a shared space populated by virtual objects, while remaining grounded in the real world. This technique is particularly powerful for educational purposes when users are collocated and can use natural means of communication (speech, gestures etc.), but can also be mixed successfully with immersive VR or remote collaboration." Hannes cites education as a potential use of this technology.

Video games

The gaming industry embraced AR technology. A number of games were developed for prepared indoor environments, such as AR air hockey, *Titans of Space*, collaborative combat against virtual enemies, and AR-enhanced pool table games.[154][155][156]



An AR mobile game using a trigger image as fiducial marker

Augmented reality allowed video game players to experience digital game play in a real-world environment. Niantic released the augmented reality mobile game *Pokémon Go*.[157] Disney has partnered with Lenovo to create the augmented reality game *Star Wars: Jedi Challenges* that works with a Lenovo Mirage AR headset, a tracking sensor and a Lightsaber controller, scheduled to launch in December 2017.[158]

Augmented Reality Gaming (ARG) is also used to market film and television entertainment properties. On 16 March 2011, BitTorrent promoted an open licensed version of the feature film *Zenith* in the United States. Users who downloaded the BitTorrent client software were also encouraged to download and share Part One of three parts of the film. On 4 May 2011, Part Two of the film was made available on VODO. The episodic release of the film, supplemented by an ARG transmedia marketing campaign, created a viral effect and over a million users downloaded the movie.[159][160][161][162]

Industrial design

AR allows industrial designers to experience a product's design and operation before completion. Volkswagen has used AR for comparing calculated and actual crash test imagery.[163] AR has been used to visualize and modify car body structure and engine layout. It has also been used to compare digital mock-ups with physical mock-ups to find discrepancies between them.[164][165]

Healthcare practice & life sciences education

Since 2005, a device called a near-infrared vein finder that films subcutaneous veins, processes and projects the image of the veins onto the skin has been used to locate veins.[166][167] AR provides surgeons with patient monitoring data in the style of a fighter pilot's heads-up display, and allows patient imaging records, including functional videos, to be accessed and overlaid. Examples include a virtual X-ray view based on prior tomography or on real-time images from ultrasound and confocal microscopy probes,[168] visualizing the position of a tumor in the video of an endoscope,[169] or radiation exposure risks from X-ray imaging devices.[170][171] AR can enhance viewing a fetus inside a mother's womb.[172] Siemens, Karl Storz and IRCAD have developed a system for laparoscopic liver surgery that uses AR to view sub-surface tumors and vessels.[173] AR has been used for cockroach phobia treatment.[174] Patients wearing augmented reality glasses can be reminded to take medications.[175] Virtual reality has been seen as a promising tool in the medical field since the 90's.[176] Augmented reality can be very helpful in the medical field.[177] It could be used to provide crucial information to a doctor or surgeon without having them take their eyes off the patient. On 30 April 2015 Microsoft announced the Microsoft HoloLens, their first attempt at augmented reality. The HoloLens has advanced through the years and is capable of projecting holograms for near infrared fluorescence based image guided surgery.[178] As augmented reality advances, it finds increasing applications in healthcare. Augmented reality and similar computer based-utilities are being used to train medical professionals.[179] In healthcare, AR can be used to provide guidance during diagnostic and therapeutic interventions e.g. during surgery. Magee et al.[180] for instance describe the use of augmented reality for medical training in simulating ultrasound guided needle placement.

Spatial immersion and interaction

Augmented reality applications, running on handheld devices utilized as virtual reality headsets, can also digitize human presence in space and provide a computer generated model of them, in a virtual space where they can interact and perform various actions. Such capabilities are demonstrated by Project Anywhere, developed by a postgraduate student at ETH Zurich, which was dubbed as an "out-of-body experience".[181][182][183]

Flight training

Building on decades of perceptual-motor research in experimental psychology, researchers at the Aviation Research Laboratory of the University of Illinois at Urbana–Champaign used augmented reality in the form of a flight path in the sky to teach flight students how to land an airplane using a flight simulator. An adaptive augmented schedule in which students were shown the augmentation only when they departed from the flight path proved to be a more effective training intervention than a constant schedule.[184][185] Flight students taught to land in the simulator with the adaptive augmentation learned to land a light aircraft more quickly than students with the same amount of landing training in the simulator but with constant augmentation or without any augmentation.[184]

Military

Augmented Reality System for Soldier ARC4 (U.S. Army 2017)

An interesting early application of AR occurred when Rockwell International created video map overlays of satellite and orbital debris tracks to aid in space observations at Air Force Maui Optical System. In their 1993 paper "Debris Correlation Using the Rockwell WorldView System" the authors describe the use of map overlays applied to video from space surveillance telescopes. The map overlays indicated the trajectories of various objects in geographic coordinates. This allowed telescope operators to identify satellites, and also to identify and catalog potentially dangerous space debris.[186]

Starting in 2003 the US Army integrated the SmartCam3D augmented reality system into the Shadow Unmanned Aerial System to aid sensor operators using telescopic cameras to locate people or points of interest. The system combined fixed geographic information including street names, points of interest, airports, and railroads with live video from the camera system. The system offered a "picture in picture" mode that allows it to show a synthetic view of the area surrounding the camera's field of view. This helps solve a problem in which the field of view is so narrow that it excludes important context, as if "looking through a soda straw". The system displays real-time friend/foe/neutral location markers blended with live video, providing the operator with improved situational awareness.

As of 2010, Korean researchers are looking to implement mine-detecting robots into the military. The proposed design for such a robot includes a mobile platform that is like a track which would be able to cover uneven distances including stairs. The robot's mine detection sensor would include a combination of metal detectors and Ground-penetrating radar to locate mines or IEDs. This unique design would be immeasurably helpful in saving lives of Korean soldiers.[187]

Researchers at USAF Research Lab (Calhoun, Draper et al.) found an approximately two-fold increase in the speed at which UAV sensor operators found points of interest using this technology.[188] This ability to maintain geographic awareness quantitatively enhances mission efficiency. The system is in use on the US Army RQ-7 Shadow and the MQ-1C Gray Eagle Unmanned Aerial Systems.

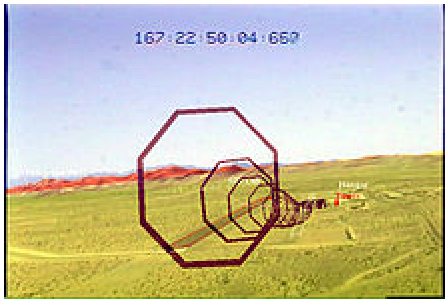
In combat, AR can serve as a networked communication system that renders useful battlefield data onto a soldier's goggles in real time. From the soldier's viewpoint, people and various objects can be marked with special indicators to warn of potential dangers. Virtual maps and 360° view camera imaging can also be rendered to aid a soldier's navigation and battlefield perspective, and this can be transmitted to military leaders at a remote command center.[189]. The combination of 360° view cameras visualization and

AR can be use on board combat vehicles and tanks as circular review system.

Circular review system of the company LimpidArmor

AR can be very effective to virtually design out the 3D topologies of munition storages in the terrain with the choice of the munitions combination in stacks and distances between them whith a visualization of risk areas[190]. The scope of AR applications also includes visualization of data from embedded munitions monitoring sensors[190].

Navigation



LandForm video map overlay marking runways, road, and buildings during 1999 helicopter flight test

The NASA X-38 was flown using a Hybrid Synthetic Vision system that overlaid map data on video to provide enhanced navigation for the spacecraft during flight tests from 1998 to 2002. It used the LandForm software whuich was useful for times of limited visibility, including an instance when the video camera window frosted over leaving astronauts to rely on the map overlays.[191] The LandForm software was also test flown at the Army Yuma Proving Ground in 1999. In the photo at right one can see the map markers indicating runways, air traffic control tower, taxiways, and hangars overlaid on the video.[192]

AR can augment the effectiveness of navigation devices. Information can be displayed on an automobile's windshield indicating destination directions and meter, weather, terrain, road conditions and traffic information as well as alerts to potential hazards in their path.[193][194][195] Since 2012, a Swiss-based company WayRay has been developing holographic AR navigation systems that use holographic optical elements for projecting all route-related information including directions, important notifications, and points of interest right into the drivers' line of sight and far ahead of the vehicle.[196][197] Aboard maritime vessels, AR can allow bridge watch-standers to continuously monitor important information such as a ship's heading and speed while moving throughout the bridge or performing other tasks.[198]

Workplace

Augmented reality may have a positive impact on work collaboration as people may be inclined to interact more actively with their learning environment. It may also encourage tacit knowledge renewal which makes firms more competitive. AR was used to facilitate collaboration among distributed team members via conferences with local and virtual participants. AR tasks included brainstorming and discussion meetings utilizing common visualization via touch screen tables, interactive digital whiteboards, shared design spaces and distributed control rooms.[199][200][201]

In industrial environments, augmented reality is proving to have a substantial impact with more and more use cases emerging across all aspect of the product lifecycle, starting from product design and new product introduction (NPI) to manufacturing to service and maintenance, to material handling and distribution. For example, labels were displayed on parts of a system to clarify operating instructions for a mechanic performing maintenance on a system.[202][203] Assembly lines benefited from the usage of AR. In addition to Boeing, BMW and Volkswagen were known for incorporating this technology into assembly lines for monitoring process improvements.[204][205][206] Big machines are difficult to maintain because of their multiple layers or structures. AR permits people to look through the machine as if with an x-ray, pointing them to the problem right away.[207]

As AR technology has evolved and second and third generation AR devices come to market, the impact of AR in enterprise continues to flourish. In the *Harvard Business Review*, Magid Abraham and Marco Annunziata discuss how AR devices are now being used to "boost workers' productivity on an array of tasks the first time they're used, even without prior training'.[208] They contend that "these technologies increase productivity by making workers more skilled and efficient, and thus have the potential to yield both more economic growth and better jobs".[208]

Broadcast and live events

Weather visualizations were the first application of augmented reality in television. It has now become common in weather casting to display full motion video of images captured in real-time from multiple cameras and other imaging devices. Coupled with 3D graphics symbols and mapped to a common virtual geospatial model, these animated visualizations constitute the first true application of AR to TV.

AR has become common in sports telecasting. Sports and entertainment venues are provided with see-through and overlay augmentation through tracked camera feeds for enhanced viewing by the audience. Examples include the yellow "first down" line seen in television broadcasts of American football games showing the line the offensive team must cross to receive a first down. AR is also used in association with football and other sporting events to show commercial advertisements overlaid onto the view of the playing area. Sections of rugby fields and cricket pitches also display sponsored images. Swimming telecasts often add a line across the lanes to indicate the position of the current record holder as a race proceeds to allow viewers to compare the current race to the best performance. Other examples include hockey puck tracking and annotations of racing car performance and snooker ball trajectories.[76][209]

Augmented reality for Next Generation TV allows viewers to interact with the programs they are watching. They can place objects into an existing program and interact with them, such as moving them around. Objects include avatars of real persons in real time who are also watching the same program.

AR has been used to enhance concert and theater performances. For example, artists allow listeners to augment their listening experience by adding their performance to that of other bands/groups of users.[210][211][212]

Tourism and sightseeing

Travelers may use AR to access real-time informational displays regarding a location, its features, and comments or content provided by previous visitors. Advanced AR applications include simulations of historical events, places, and objects rendered into the landscape.[213][214][215]

AR applications linked to geographic locations present location information by audio, announcing features of interest at a particular site as they become visible to the user.[216][217][218]

Companies can use AR to attract tourists to particular areas that they may not be familiar with by name. Tourists will be able to experience beautiful landscapes in first person with the use of AR devices. Companies like Phocuswright plan to use such technology to expose lesser known but beautiful areas of the planet, and in turn, increase tourism. Other companies such as Matoke Tours have already developed an application where the user can see 360 degrees from several different places in Uganda. Matoke Tours and Phocuswright have the ability to display their apps on virtual reality headsets like the Samsung VR and Oculus Rift.[219]

Translation

AR systems such as Word Lens can interpret the foreign text on signs and menus and, in a user's augmented view, re-display the text in the user's language. Spoken words of a foreign language can be translated and displayed in a user's view as printed subtitles.[220][221][222]

Music

It has been suggested that augmented reality may be used in new methods of music production, mixing, control and visualization.[223][224][225][226]

A tool for 3D music creation in clubs that, in addition to regular sound mixing features, allows the DJ to play dozens of sound samples, placed anywhere in 3D space, has been conceptualized.[227]

Leeds College of Music teams have developed an AR app that can be used with Audient desks and allow students to use their smartphone or tablet to put layers of information or interactivity on top of an Audient mixing desk.[228]

ARmony is a software package that makes use of augmented reality to help people to learn an instrument.[229]

In a proof-of-concept project Ian Sterling, an interaction design student at California College of the Arts, and software engineer Swaroop Pal demonstrated a HoloLens app whose primary purpose is to provide a 3D spatial UI for cross-platform devices—the Android Music Player app and Arduino-controlled Fan and Light—and also allow interaction using gaze and gesture control.[230][231][232][233]

AR Mixer is an app that allows one to select and mix between songs by manipulating objects—such as changing the orientation of a bottle or can.[234]

In a video, Uriel Yehezkel demonstrates using the Leap Motion controller and GECO MIDI to control Ableton Live with hand gestures and states that by this method he was able to control more than 10 parameters simultaneously with both hands and take full control over the construction of the song, emotion and energy.[235][236]

A novel musical instrument that allows novices to play electronic musical compositions, interactively remixing and modulating their elements, by manipulating simple physical objects has been proposed.[237]

A system using explicit gestures and implicit dance moves to control the visual augmentations of a live music performance that enable more dynamic and spontaneous performances and—in combination with indirect augmented reality—leading to a more intense interaction between artist and audience has been suggested.[238]

Research by members of the CRIStAL at the University of Lille makes use of augmented reality to enrich musical performance. The ControllAR project allows musicians to augment their MIDI control surfaces with the remixed graphical user interfaces of music software.[239] The Rouages project proposes to augment digital musical instruments to reveal their mechanisms to the audience and thus improve the perceived liveness.[240] Reflets is a novel augmented reality display dedicated to musical performances where the audience acts as a 3D display by revealing virtual content on stage, which can also be used for 3D musical interaction and collaboration.[241]

Snapchat

Snapchat users have access to augmented reality in the company's instant messaging app through use of camera filters. In September 2017, Snapchat updated its app to include a camera filter that allowed users to render an animated, cartoon version of themselves called "Bitmoji". These animated avatars would be projected in the real world through the camera, and can be photographed or video recorded.[242] In the same month, Snapchat also announced a new feature called "Sky Filters" that will be available on its app. This new feature makes use of augmented reality to alter the look of a picture taken of the sky, much like how users can apply the app's filters to other pictures. Users can choose from sky filters such as starry night, stormy clouds, beautiful sunsets, and rainbow.[243]

The dangers of AR

Reality modifications

In a paper titled "Death by Pokémon GO”, researchers at Purdue University's Krannert School of Management claim the game caused "a disproportionate increase in vehicular crashes and associated vehicular damage, personal injuries, and fatalities in the vicinity of locations, called PokéStops, where users can play the game while driving."[244] Using data from one municipality, the paper extrapolates what that might mean nationwide and concluded "the increase in crashes attributable to the introduction of Pokémon GO is 145,632 with an associated increase in the number of injuries of 29,370 and an associated increase in the number of fatalities of 256 over the period of July 6, 2016, through November 30, 2016." The authors extrapolated the cost of those crashes and fatalities at between $2bn and $7.3 billion for the same period. Furthermore, more than one in three surveyed advanced Internet users would like to edit out disturbing elements around them, such as garbage or graffiti.[245] They would like to even modify their surroundings by erasing street signs, billboard ads, and uninteresting shopping windows. So it seems that AR is as much a threat to companies as it is an opportunity. Although, this could be a nightmare to numerous brands that do not manage to capture consumer imaginations it also creates the risk that the wearers of augmented reality glasses may become unaware of surrounding dangers. Consumers want to use augmented reality glasses to change their surroundings into something that reflects their own personal opinions. Around two in five want to change the way their surroundings look and even how people appear to them.

Next, to the possible privacy issues that are described below, overload and over-reliance issues are the biggest danger of AR. For the development of new AR-related products, this implies that the user-interface should follow certain guidelines as not to overload the user with information while also preventing the user from over-relying on the AR system such that important cues from the environment are missed.[246] This is called the virtually-augmented key.[246] Once the key is ignored, people might not desire the real world anymore.

Privacy concerns

The concept of modern augmented reality depends on the ability of the device to record and analyze the environment in real time. Because of this, there are potential legal concerns over privacy. While the First Amendment to the United States Constitution allows for such recording in the name of public interest, the constant recording of an AR device makes it difficult to do so without also recording outside of the public domain. Legal complications would be found in areas where a right to a certain amount of privacy is expected or where copyrighted media are displayed.

In terms of individual privacy, there exists the ease of access to information that one should not readily possess about a given person. This is accomplished through facial recognition technology. Assuming that AR automatically passes information about persons that the user sees, there could be anything seen from social media, criminal record, and marital status.[247]

Notable researchers

- Ivan Sutherland invented the first VR head-mounted display at Harvard University.
- Steve Mann formulated an earlier concept of mediated reality in the 1970s and 1980s, using cameras, processors, and display systems to modify visual reality to help people see better (dynamic range management), building computerized welding helmets, as well as "augmediated reality" vision systems for use in everyday life. He is also an adviser to Meta.[248]
- Louis Rosenberg developed one of the first known AR systems, called Virtual Fixtures, while working at the U.S. Air Force Armstrong Labs in 1991, and published the first study of how an AR system can enhance human performance.[249] Rosenberg's subsequent work at Stanford University in the early 90's, was the first proof that virtual overlays when registered and presented over a user's direct view of the real physical world, could significantly enhance human performance.[250][251][252]
- Mike Abernathy pioneered one of the first successful augmented video overlays (also called hybrid synthetic vision) using map data for space debris in 1993,[186] while at Rockwell International. He co-founded Rapid Imaging Software, Inc. and was the primary author of the LandForm system in 1995, and the SmartCam3D system.[191][192] LandForm augmented reality was successfully flight tested in 1999 aboard a helicopter and

SmartCam3D was used to fly the NASA X-38 from 1999–2002. He and NASA colleague Francisco Delgado received the National Defense Industries Association Top5 awards in 2004.[253]

- Steven Feiner, Professor at Columbia University, is the author of a 1993 paper on an AR system prototype, KARMA (the Knowledge-based Augmented Reality Maintenance Assistant), along with Blair MacIntyre and Doree Seligmann. He is also an advisor to Meta.[254]
- Tracy McSheery, of Phasespace, developer in 2009 of wide field of view AR lenses as used in Meta 2 and others.[255]
- S. Ravela, B. Draper, J. Lim and A. Hanson developed a marker/fixture-less augmented reality system with computer vision in 1994. They augmented an engine block observed from a single video camera with annotations for repair. They use model-based pose estimation, aspect graphs and visual feature tracking to dynamically register model with the observed video.[256]
- Francisco Delgado is a NASA engineer and project manager specializing in human interface research and development. Starting 1998 he conducted research into displays that combined video with synthetic vision systems (called hybrid synthetic vision at the time) that we recognize today as augmented reality systems for the control of aircraft and spacecraft. In 1999 he and colleague Mike Abernathy flight-tested the LandForm system aboard a US Army helicopter. Delgado oversaw integration of the LandForm and SmartCam3D systems into the X-38 Crew Return Vehicle.[191][192] In 2001, Aviation Week reported NASA astronaut's successful use of hybrid synthetic vision (augmented reality) to fly the X-38 during a flight test at Dryden Flight Research Center. The technology was used in all subsequent flights of the X-38. Delgado was co-recipient of the National Defense Industries Association 2004 Top 5 software of the year award for SmartCam3D.[253]
- Bruce H. Thomas and Wayne Piekarski developed the Tinmith system in 1998.[257] They along with Steve Feiner with his MARS system pioneer outdoor augmented reality.
- Mark Billinghurst is Director of the HIT Lab New Zealand (HIT Lab NZ) at the University of Canterbury in New Zealand and a notable AR researcher. He has produced over 250 technical publications and presented demonstrations and courses at a wide variety of conferences.
- Reinhold Behringer performed important early work (1998) in image registration for augmented reality, and prototype wearable testbeds for augmented reality. He also co-organized the First IEEE International Symposium on Augmented Reality in 1998 (IWAR'98), and co-edited one of the first books on augmented reality.[258][259][260]
- Felix G. Hamza-Lup, Larry Davis and Jannick Rolland developed the 3D ARC display with optical see-through head-warned display for AR visualization in 2002.[261]
- Dieter Schmalstieg and Daniel Wagner developed a marker tracking systems for mobile phones and PDAs in 2009.[262]

History

- 1901: L. Frank Baum, an author, first mentions the idea of an electronic display/spectacles that overlays data onto real life (in this case 'people'). It is named a 'character marker'.[263]
- 1957–62: Morton Heilig, a cinematographer, creates and patents a simulator called Sensorama with visuals, sound, vibration, and smell.[264]
- 1968: Ivan Sutherland invents the head-mounted display and positions it as a window into a virtual world.[265]
- 1975: Myron Krueger creates Videoplace to allow users to interact with virtual objects.
- 1980: The research by Gavan Lintern of the University of Illinois is the first published work to show the value of a heads up display for teaching real-world flight skills.[184]
- 1980: Steve Mann creates the first wearable computer, a computer vision system with text and graphical overlays on a photographically mediated scene.[266] See EyeTap. See Heads Up Display.
- 1981: Dan Reitan geospatially maps multiple weather radar images and space-based and studio cameras to earth maps and abstract symbols for television weather broadcasts, bringing a precursor concept to augmented reality (mixed real/graphical images) to TV.[267]
- 1987: Douglas George and Robert Morris create a working prototype of an astronomical telescope-based "heads-up display" system (a precursor concept to augmented reality) which superimposed in the telescope eyepiece, over the actual sky images, multi-intensity star, and celestial body images, and other relevant information.[268][269]
- 1990: The term 'Augmented Reality' is attributed to Thomas P. Caudell, a former Boeing researcher.[270]
- 1992: Louis Rosenberg developed one of the first functioning AR systems, called Virtual Fixtures, at the United States Air Force Research Laboratory—Armstrong, that demonstrated benefit to human perception.[271]
- 1992: Steven Feiner, Blair MacIntyre and Doree Seligmann present an early paper on an AR system prototype, KARMA, at the Graphics Interface conference.

- 1993: Mike Abernathy, et al., report the first use of augmented reality in identifying space debris using Rockwell WorldView by overlaying satellite geographic trajectories on live telescope video.[186]
- 1993 A widely cited version of the paper above is published in Communications of the ACM – Special issue on computer augmented environments, edited by Pierre Wellner, Wendy Mackay, and Rich Gold.[272]
- 1993: Loral WDL, with sponsorship from STRICOM, performed the first demonstration combining live AR-equipped vehicles and manned simulators. Unpublished paper, J. Barrilleaux, "Experiences and Observations in Applying Augmented Reality to Live Training", 1999.[273]
- 1994: Julie Martin creates first 'Augmented Reality Theater production', Dancing In Cyberspace, funded by the Australia Council for the Arts, features dancers and acrobats manipulating body–sized virtual object in real time, projected into the same physical space and performance plane. The acrobats appeared immersed within the virtual object and environments. The installation used Silicon Graphics computers and Polhemus sensing system.
- 1995: S. Ravela et al. at University of Massachusetts introduce a vision-based system using monocular cameras to track objects (engine blocks) across views for augmented reality.
- 1998: Spatial Augmented Reality introduced at University of North Carolina at Chapel Hill by Ramesh Raskar, Welch, Henry Fuchs.[61]
- 1999: Frank Delgado, Mike Abernathy et al. report successful flight test of LandForm software video map overlay from a helicopter at Army Yuma Proving Ground overlaying video with runways, taxiways, roads and road names.[191][192]
- 1999: The US Naval Research Laboratory engages on a decade-long research program called the Battlefield Augmented Reality System (BARS) to prototype some of the early wearable systems for dismounted soldier operating in urban environment for situation awareness and training.[274]
- 1999: NASA X-38 flown using LandForm software video map overlays at Dryden Flight Research Center.[275]
- 2000: Rockwell International Science Center demonstrates tetherless wearable augmented reality systems receiving analog video and 3-D Audio over radio-frequency wireless channels. The systems incorporate outdoor navigation capabilities, with digital horizon silhouettes from a terrain database overlain in real time on the live outdoor scene, allowing visualization of terrain made invisible by clouds and fog.[276][277]
- 2004: Outdoor helmet-mounted AR system demonstrated by Trimble Navigation and the Human Interface Technology Laboratory (HIT lab).[100]
- 2008: Wikitude AR Travel Guide launches on 20 Oct 2008 with the G1 Android phone.[278]
- 2009: ARToolkit was ported to Adobe Flash (FLARToolkit) by Saqoosha, bringing augmented reality to the web browser.[279]
- 2010: Design of mine detection robot for Korean mine field.[187]
- 2012: Launch of Lyteshot, an interactive AR gaming platform that utilizes smart glasses for game data
- 2013: Meta announces the Meta 1 developer kit.[280][281]
- 2015: Microsoft announces Windows Holographic and the HoloLens augmented reality headset. The headset utilizes various sensors and a processing unit to blend high definition "holograms" with the real world.[282]
- 2016: Niantic released *Pokémon Go* for iOS and Android in July 2016. The game quickly became one of the most popular smartphone applications and in turn spikes the popularity of augmented reality games.[283]
- 2017: Magic Leap announces the use of Digital Lightfield technology embedded into the Magic Leap One headset. The creators edition headset includes the glasses and a computing pack worn on your belt.[284]

See also

- Alternate reality game
- ARTag
- Augmented browsing
- Augmented reality-based testing
- Augmented web
- Automotive head-up display
- Bionic contact lens
- Brain in a vat
- Computer-mediated reality
- Cyborg
- EyeTap

- Head-mounted display
- Holography
- Lifelike experience
- List of augmented reality software
- Magic Leap
- Mixed reality
- Optical head-mounted display
- Simulated reality
- Smartglasses
- Structure from motion
- Transreality gaming
- Video mapping
- Viractualism
- Virtual reality
- Visuo-haptic mixed reality
- Wearable computing

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