Overview of Immersive Technology: Terminology, State of the Art, and APL Efforts

Scott D. Simpkins, Patrick D. Allen, and Nicholas W. DeMatt

AR VR
MR

ABSTRACT

Immersive technologies have roots dating back to the 1800s. The Johns Hopkins University Applied Physics Laboratory (APL) has been exploring how to use these technologies to meet critical national needs for decades. Today these technologies constitute an entire domain, replete with its own lexicon, and commercially available tools have become more capable and less expensive. There are use cases for immersive technologies in just about every field, from the entertainment industry to health care to defense. This article reviews the history of immersive technologies, clarifies some of the terminology used to describe the technologies, and presents the current state of the art. It then presents 15 examples of APL work in a wide range of application areas including intelligence, military, first responders, medical, space, human factors, education, and research, and it concludes with some additional use cases.

INTRODUCTION

Immersive displays have a long history. The first entrée into immersive displays hearkens back to 1838, with the invention of the Wheatstone stereoscope that presented users a 3-D perspective relying on still images.[1] Advances in computing power and data availability led to augmented reality (AR) head-mounted displays (HMDs) in the 1960s.[2] By the late 20th century, the US Air Force had made significant developments in AR with heads-up displays (HUDs) in combat aircraft cockpits.[3] The blanket term *mixed reality* (MR) is about 25 years old, first appearing in a paper describing a reality–virtuality continuum.[4]

Today there are a multitude of technologically enhanced "realities." Although immersive experiences and technologies themselves are not all necessarily new, they now constitute an entire domain with a dynamic landscape of services, vendors, and consumers and a broad spectrum of hardware, software, capabilities, and uses. For example, the entertainment industry, an early adopter, has flooded the market with immersive games. Other industries, from health care to military and law enforcement to architecture, are catching on, using immersive technology and experiences to interact with their communities, to train their personnel,[5] and to visualize complex designs, to name just a few uses.

APL has been engaged in immersive technology for more than two decades. As the domain grows and technologies advance, APL staff members working in many disciplines are developing and testing innovative immersive applications that support the missions of Lab sponsors and the nation.

We begin this article by defining the various terms used in the industry and in this issue of the *Johns Hopkins APL Technical Digest*. Next we present a brief history of the field through its current state. The latter part of this article summarizes technical work APL teams are doing within the domain, centered on the primary features and benefits of virtual reality (VR), AR, and MR. We conclude with some practical applications of immersive experiences and technologies, highlighting their utility to APL and its sponsors.

TERMINOLOGY AND HISTORY

Immersive technology is a vast multidimensional discipline giving rise to a unique lexicon describing various subcategories within the field—VR, AR, MR, blended reality, enhanced reality, augmented virtuality, and others. These terms are vague and often overlap intentionally. Adding to the confusion is the torrent of buzzwords, hype, and marketing from companies (both large and small) looking to make their mark in a nascent multi-billion-dollar industry. In some cases, corporate marketing and branding has claimed exclusivity for specific terms. The industry itself struggles with an onslaught of labels and descriptors for this expansive domain. It can be difficult to determine what one term means for a broad audience (i.e., to differentiate between various "realities").

The term *XR* emerged to encompass all the subcategories and descriptors. This catchall term is sometimes defined as extended reality and has also been defined as cross reality or {whatever} reality. Expressed with the generic *X*, this newest term implies a variable boundary with opportunities for any mixture of designed user experiences. We define XR as a broad integration of various applications that extend beyond viewed content to include sensors, wearables, prosthetics, and artificial intelligence.

Despite the abundance of terms, immersing users in an enhanced, artificial environment comes down to two methods: (1) present an entirely encompassing view where 100% of the visual range is created or (2) apply enhanced content to the user's existing visual range. The varying degree to which these methods are applied, or combined, is what keeps adding new terms to the industry's lexicon. While hardware devices themselves may blend one into another, there are ultimately two key modalities: either the immersive device is taking users to another place (real or imagined) or the device is delivering digital content into users' physical worlds. These two modalities are complementary, but distinct, and both have a variety of uses in the public, private, and academic sectors. A brief description of the two dominant categories is presented here for clarity.

Virtual reality (VR) describes interactions in an entirely artificial, immersive, constructed environment. VR strives to present users an entirely detached environment absent interactions with their physical surroundings or "real world." VR users often wear HMDs. Monitoring sensors for these systems are generally designed to measure user motion with HMDs so software can present a world consistent with the operator's senses. A full user experience can involve haptic feedback, with sensors emulating heat, touch, pressure, and wind uniquely tuned to match, and enhance, the wearer's actions in VR. The more an operator can fully participate in an immersive cognitive experience, the better the experience will be.

The highest-quality and best-funded VR applications today are for entertainment, designed to engage users with an artificial environment while they interact with provided content. Examples include applications that immerse users in undersea worlds, within historic battles, or in collaborative work spaces. The gaming industry, realizing the value of immersing users in well-scripted environments, was an early adopter of VR. VR gaming consoles in wide use today had their beginnings in Virtual Boy, Nintendo's 1995 foray into the immersive environment. If you don't remember Virtual Boy, you're not alone; it was on the market, at more than $175, for less than a year but represents the first serious attempt to market VR gaming to the public.

Augmented reality (AR) differs from VR in that it relies on the real world as a substrate. AR places computer-generated content in the user's normal field of view. Professional industries are adopting AR for a variety of design, planning, and educational purposes. Applying these types of overlays requires data availability and processing power driven by quick responsiveness to apply content to users' immediate surroundings with imperceptible delay.

AR hardware takes many forms, including headsets, mobile device applications, and even projection-based CAVEs. (CAVE is a recursive acronym for Cave Automatic Virtual Environment, describing a VR display room—essentially a 10-ft. cube—first developed at the University of Illinois at Chicago. User movement is tracked and VR content projected on the walls of the cube from the outside, allowing users to move freely, unencumbered.) AR examples include AR eyeglasses, games like Pokémon GO for mobile devices, and multiple personal navigation applications. AR vaulted into the public conversation when Google released Google Glass in 2013 and became much more commonplace with improvement in mobile device capabilities.

Modern computing, sensing, graphics, and display quality and modalities have pushed immersive devices and applications beyond a single-dimensional categorization to a much broader and diverse multidimensional description of capabilities. The ever-widening spectrum of technology and applications (see Figure 1) has grown to effectively integrate with parallel technology, making immersive applications part of capability suites available to developers, engineers, managers, and enthusiasts alike.

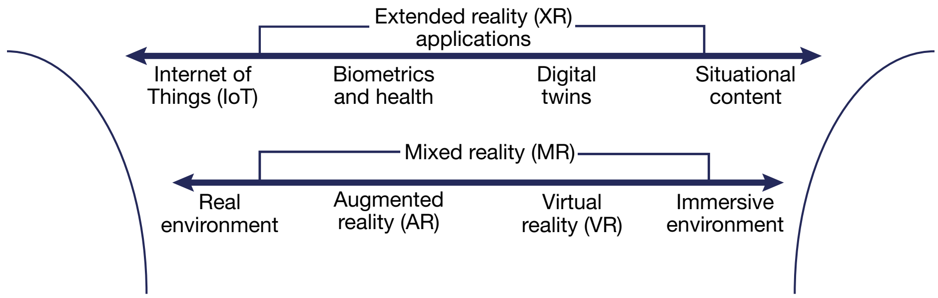

Figure 1. The expansive growth and integrated use of immersive technologies. (Graphic adapted, with permission, from reality–virtuality continuum described by Milgram and Kishino[4] in 1994.)

THE STATE OF XR TODAY

Today, VR gaming is everywhere, entry-point pricing is affordable for many, and immersive graphics are superb. Consumers can buy a VR headset in the style of Google Cardboard for $10 or less and, by using free applications for smartphones, enjoy a worthwhile entry-level VR experience. For a few hundred dollars, systems on the market allow full freedom of movement, high-quality user controls, and an untethered experience. The market is filled with early-adopter hardware, like Microsoft's AR HoloLens, and software marketing mobile AR applications with popular offerings.

Diverse professional interests are entering the domain, resulting in services to support marketing, facility visualization, and computer-aided design (CAD), to name just a few. Although using computer simulations for various kinds of professional work is not new, XR today allows designers to view, adjust, and even stand inside of processes. Haptic gloves, vests, and suits add sensory learning, reflex response, and muscle memory to training for hazardous work. Where and how the professional market closes the gap between entertainment and "serious" applications is not fully defined yet, but the growing XR community has recorded familiar successes.

Many people have come into contact with XR at museums and exhibits. Curators are early adopters, using this technology for "living" demonstrations of dinosaurs or space walks for example. Planetariums have embraced XR to magnify the immersed perspective on space. Commercial and military flight simulators are another recognizable example of XR. Pilots train on multiple aircraft and react to extreme challenges with great success. These systems tilt, move, and twist, replicating aircraft movements. Furniture and clothing retailers (e.g., IKEA and Timberland) sponsor AR applications to overlay a couch in your living room or a new piece of clothing on a photo of your body. Customers view their options inserted into their busy schedules. Target Corporation attributes a doubling of Christmas tree sales to its AR application.[6] In one newsworthy application, a well-known company outfitted a seemingly routine city bus stop with AR technology, grabbing the attention of commuters waiting inside the transparent bus stop walls with displays of fantastical 3-D scenes coming toward them.

Engineers are using XR in prototype testing environments to simulate and test many performance characteristics of a part, process, or mechanism. Just as exciting is the ability for multiple users to participate in a collaborative XR session. Some AR applications allow engineers to perform a design review, sharing a single AR experience. Even more exciting is that these same design reviews can be done remotely, meaning participants join without all coming together in a single location. Then when the product is fielded, the same engineer can provide remote assistance to the operator by using what are termed "remote assistance applications." Uploaded building schematics available to AR applications provide visible overlays for electrical circuits, HVAC pathways, and a building's structural components during construction. Health care and medicine also benefit from incorporation of VR in patient treatment and provider training. Health care professionals are using XR to treat posttraumatic stress disorder[7] and certain phobias.[8] Doctors present carefully tailored situations with controlled conditions to help patients explore their feelings in environments they know are safe. The rapidly changing and often chaotic scenes a paramedic may encounter are being simulated in XR, creating realistic field conditions for training. This immersive, experiential approach helps prepare responders to better cope with confusion and chaos and can expose them to a range of scenarios not easily replicated elsewhere. Overall, XR applications stimulate the brain to think and behave as though it is interacting with the physical world, enhancing attention, memory, and learning while in some cases lowering risk of harm and reducing costs of processes.

XR Is Smart Business

With any new technology, the question posed by those who seek to understand it is: What is the benefit of using this technology? The answer, of course, is: It depends. It depends largely on the area to which the technology is being applied and the anticipated target audience. XR is big business, with growing opportunities and requirements for organizations adopting it.

Global business leaders anticipate major impacts by integrating XR into previously uncharted domains. Nearly half of the expected XR demand signal over the next decade is professional applications. One-third of these are in traditional technology domains for APL's sponsoring organizations (see Figure 2). Investment by health care industries is anticipated to reach $5.1 billion by 2025, representing just under 20% of the XR market. APL has a long tradition of finding value in emerging concepts and developing game-changing technology. XR is ready for widespread professional adoption.

We believe the market is still maturing, having only recently made it over what Gartner, the world's leading research and advisory company, calls the Peak of Inflated Expectations (see Figure 3).[10] As such, start-ups have recently flooded a market slow to respond to the unrealistic expectations of the early cycle. Large experienced technology companies such as Google and Microsoft and other early adopters, such as Valve, Oculus, and HTC, continue to research and market updated products, investing in the long term. Although broad-market household adoption has not occurred at the pace expected a few years ago, the technology base has grown and products have proven especially useful for automotive, industrial, energy, medical, scientific, and training industries.

Gartner has positioned MR, AR, HMDs, and VR in the Trough of Disillusionment of its Hype Cycle for Display and Vision, 2020.[11] Nonetheless, the domain is still new enough that there is a dynamic landscape of services and start-ups, and the first business successes and failures have only been recently identified. Consumers want to believe in the utility of XR—that these technologies will enhance work and life.

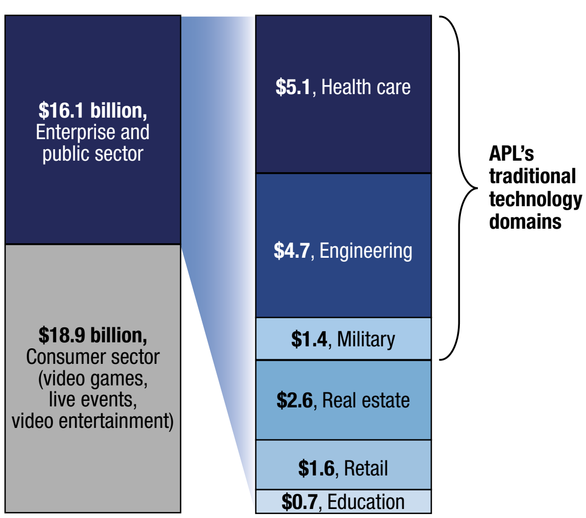

Figure 2. Predicted market for XR technology by 2025. APL's traditional sponsor base is well represented in various communities forecasted to leverage XR technologies within the next 5 years. (Data from Goldman Sachs Investment Research.[9])

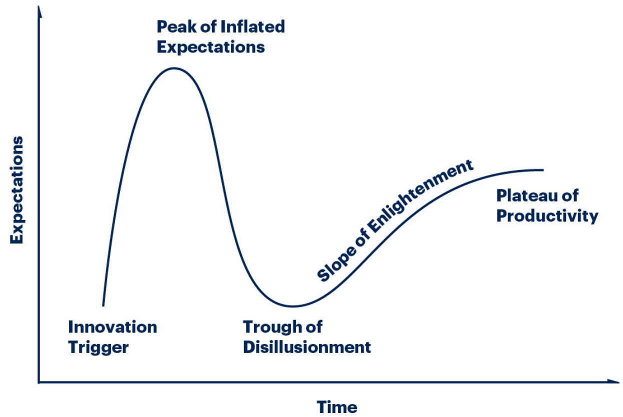

Figure 3. The Gartner Hype Cycle. "Gartner Hype Cycles provide a graphic representation of the maturity and adoption of technologies and applications, and how they are potentially relevant to solving real business problems and exploiting new opportunities."[10]

Current Limitations of XR

Not everything in the XR domain is rife with success. In many ways the industry is discovering shortfalls and is still growing and learning lessons from failed attempts. The first version of Microsoft Kinect did not gain popularity primarily because interaction with the environment required the user to perform unnatural, laborious gestures. Over time the technology has improved, with new high-end devices incorporating more natural gestures. Still, although systems continue to improve, there are many challenges ahead.

For VR, designed safety protocols are intended to keep players safe while immersed—away from walls, edges, and other risks to physical safety. But these protocols are difficult to enforce and users frequently mismanage or ignore them as their brains accept the digital world and lose track of the physical one. Broken ceiling fans, dented walls, and bruised shins are all sirens for much needed improvement. (A 44-year-old Moscow man died in 2017 when he fell using VR.[12] He is believed to be the only fatality attributed directly to XR.) Locomotion remains a significant problem in VR, leading to unnatural or unintuitive means of maneuvering within virtual environments as operators are challenged to interact with an environment disjoint from their physical space.

Occasionally, AR presents interactive items such as levers or buttons. These are projected on a real-world backdrop but are difficult to anchor in any physical way within the interface, leaving users to grope toward floating virtual objects while standing in the physical world. At the very least, this is socially awkward and certainly frustrating. Development of user interfaces that present selectable items as more abstract (i.e., things we do not expect to be stationary) is underway.

Fidelity is a huge issue for XR developers. Near photorealistic graphics are available to most developers, but the algorithms that make synthetic avatars look "real" are still very far from making them interact realistically. The so-called uncanny valley[13] effect has proven hard to overcome. When a character appears very humanlike, viewers focus on any nonhuman characteristics to the point that they feel unsettled or even repulsed. Graphical representations of artificial content, especially artificial people that interact directly with users and are designed to be responsive to users, are sometimes deliberately stylized to avoid this effect. For example, video avatars expected to be directly responsive to the user often wear glasses or helmets to hide their eyes or obscure facial expressions.

Another challenge is cost. XR content can be very expensive to create and it cannot be directly ported or transferred from existing sources. While many of the art assets from traditional video games can be reused in other XR applications, to create a quality experience, developers must redesign and rebuild applications. In particular, player interactions often need to be redesigned to make an experience intuitive and provide the necessary immersive perspective. Lastly, the sense of immersion is usually limited to visual and auditory senses, with perhaps some controller vibrations. The near-future XR systems will take advantage of haptics and extrasensory inputs but currently cost thousands of dollars.

APL EFFORTS

APL has been engaged in immersive technology for more than two decades. The Lab began with a Second Life account and grew with the industry to establish multi-user virtual environments (MUVEs) relying on open-source software to bring VR to APL staff and sponsors and also to instruction at the Whiting School of Engineering. A 1994 issue of the *Digest* is devoted to discussion of synthetic environments. It describes a 3-D graphics display system used for command and control in air defense;[14] a system using an HMD to assist individuals with impaired vision;[15] simulation and visualization of blood flow;[16] and stereoscopic displays;[17] as well as research into humans' perceptual and cognitive abilities and limitations and how they relate to immersive experiences.[18,19]

With the number of XR technologies and their rapid evolution, today APL is helping its sponsors navigate through the landscape by developing and testing XR applications that support their missions. This issue of the *Digest* describes some of these efforts from the past 10 years, focusing on VR, AR, and MR technologies. (Because of their more recent emergence, newer technologies such as extended reality and augmented virtualization are not covered.)

Some of the application areas highlighted in the issue include **intelligence**, **military**, **first responders**, **medical**, **space**, **human factors**, **education**, and **research**. Many efforts span application areas and have the potential to be expanded to others. Each article, summarized below, includes icons that indicate the XR technology (VR, AR, MR, or some combination), and select articles are featured in immersive experiences that a reader can access with only a browser and the camera on their smart device.

- **Building an asset pipeline to create immersive experiences:** Taking a CAD model into a game engine to create an immersive experience requires a nominal asset pipeline, including best practices.
- **Data analysis of point cloud data:** Proto-HEAD is an AR proof of concept to visualize and interact with 3-D data using the Microsoft HoloLens. This application renders 3-D data as a point cloud contained within an interactive 3-D wire cube that can be placed onto physical surfaces and resized if necessary. Its goal was to assess whether AR significantly improves simulation and data analysis over using a PC workstation.
- **War room and data analysis:** Minard, a VR platform, provides analysts with a collaborative and private virtual environment in which they can interact with and study complex and noisy data such as alliances, the transit of individuals or groups through 3-D space, and the evolution of relationships through time.
- **Multiplatform visualization of intelligence data:** Minerva is a proof-of-concept multiplatform (web, mobile, VR) visualization suite for intelligence data.
- **Projecting sensed emotional cues on an individual:** IN:URfACE is a prototype AR system that accentuates the expressions of an emoting individual by overlaying real-time psychophysiological information on the face.
- **Reconnaissance:** This system combines AR and lidar as a step toward giving warfighters x-ray vision of their surroundings, letting them see the enemy behind physical obstacles in the environment.
- **Overlay of previous state of a damaged urban area:** This system uses architectural records to create an MR overlay for goggles, showing the world as it was before a damaging event.
- **Overlay of sensor readings for situational awareness:** The Novel Perception system collects signals from a variety of sensors, synchronizes them in real

time, registers them in real space, and then overlays them onto the real world by display through an MR headset.

- **Prosthetics testing and training:** AR technology has been integrated into APL's prosthetic and assistive capabilities to improve performance, intuitiveness, and user experience.
- **Anthropomorphic test device (for blast effects):** HoloLens applications enhance demonstration and understanding of a crash test dummy that was purpose-built to help the Army understand underbody-blast protection.
- **Spacecraft design and testing:** Digital transformation using XR was applied to the design, fabrication, integration, and testing of Parker Solar Probe and Europa Clipper.
- **Space situational awareness:** ARMOUR X is an application for visualizing Earth-orbiting resident space objects and associated attributes in an interactive and collaborative setting using the Microsoft HoloLens AR device.
- **Preconstruction visualization:** Using the HTC VIVE Pro, users can navigate and tour the interior and exterior of a building at APL before construction is completed.
- **STEM outreach and education:** Commissioned by the Office of Naval Research, a STEM (science, technology, engineering, and mathematics) workshop used the virtual Modular Prosthetic Limb along with VR and MR technology to educate young relatives of wounded warriors about prosthetics, and to inspire them to pursue STEM careers.
- **Cooperative puzzle solving in research on trust:** ESCAPE with PARTNER is a two-player cooperative VR puzzle-platform game developed for the experimental study of trust, where players must coordinate nonverbally to jointly overcome challenges that are insurmountable when attempted alone.

WAY FORWARD: OTHER PRACTICAL USE CASES

The articles described above offer a glimpse into recent APL efforts in the realm of XR. These technologies are foundational for future technology advances that yesterday were considered science fiction. The use cases described below are a perspective on the art of the possible, addressing a near-term 5- to 10-year future. They are not meant to be all inclusive.

Case 1: Data analysis performed in VR on data collected from an operational environment. In this use case, data are merged for decision-makers and presented on traditional or multidimensional displays. The operations center is constructed in VR such that anyone from any location can join the environment and work with hundreds of others in an unconstrained, unbounded space. The mayor, fire chief, police chief, and National Guard use credentialed accounts to join and collaborate through tailored content displays in VR. The ability for a user to see (within the VR) and go to the person or organization they are working with in an operation is essential. It also helps preclude lack of common communications channels between coordinating organizations. With advancements in the availability, portability, and comfort of VR displays (and the ability to use mobile devices as VR displays), it will be as easy to join the virtual operational space as it is to join a videoconference today.

Case 2: An XR suite that supports emergency response. This use case involves an AR component where police officers, paramedics, and firefighters wear special glasses and see information relevant to their immediate surroundings and tasks. Police officers might see crime statistics tailored for the street they are on; paramedics might see response times or hospital availability in the area; and firefighters might see the temperature of or distance to a fire or coworkers' locations. A responding police officer's HUD might highlight the fastest route to a crime scene. Emergency response managers might see a common operational picture in a virtual control center. With AR's geospatial component, managers can push information to everyone within a region as needed to share information affecting them all.

Case 3: Programming and control of robots. Most robots today are very difficult to program and control. They generally require line of sight from an operator. In this use case, an all-terrain robot is operated by a user observing a virtual recreation of the surrounding environment through a VR interface with content created from sensors on the robot. Remote embodiment of a robot allows for intuitive and fluent action in hazardous areas that are too hot, poisonous, or otherwise dangerous for humans. Imagine machines with technology to see through smoke, identify hot spots, find/recognize victims, construct a live map of a dangerous environment, and provide a means for an operator to take effective action in a broad variety of operational scenarios.

Case 4: Distant collaboration and conferencing. Assembling everyone interested in an activity at one location is often infeasible. Organizers need a capability allowing people to participate in meetings, conferences, and social activities for which space, cost, or social distancing are critical considerations. XR technology is a proven alternative that reduces cost and risk. Users have unique access through virtual participation, allowing significantly enhanced content engagement, freedom of movement, and immersive demonstrations. VR musical concerts and sporting events have proven the viability of this approach. The utility of applications for commercial and professional use was on full display during the COVID-19 pandemic. Global content providers and consumers alike are prepared to accept this form of collaborative business model.

As with all new technologies, researchers are investigating what, if any, health risks may be associated with using XR. Although it is not a topic explored in this issue of the *Digest*, many published papers are devoted to the topic. Anyone considering the use of XR-related technologies should read reputable publications on potential risks.

CONCLUSION

The domain we describe as XR is potentially unbounded. Supporting technology for computational power, graphics, data sharing, and usability have no perceived ceiling today. Costs continue to fall with advances in technology and increased adoption by consumers and professional industries. Major issues confronting development seem resolvable and mainstream public acceptance is increasing. XR speaks to the interests of a new generation of professional—a generation weaned on global connectivity, smartphones, and electronic experiences, with an intuitive appreciation for digital content. The technology is convenient for recruiting new workers, offering an affordable and readily available way to inform, design, experiment, and collaborate.

Throughout this issue of the *Digest*, you will read examples of primary research, engineering design, and product testing. The topics are contemporary and often cutting edge; the authors early explorers in the field. These collected articles will take you on a journey across various realities and applied technologies as APL works to deliver the future of reality.

REFERENCES

1. C. Thompson, "Stereographs were the original virtual reality," *Smithsonian Mag.*, Oct. 2017, https://www.smithsonianmag.com/innovation/sterographs-original-virtual-reality-180964771/.
2. I. E. Sutherland, "A head-mounted three dimensional display," in *Proc. ACM Fall Joint Computer Conf.*, part I, Dec. 9–11, 1968, pp. 757–764.
3. H. L. Task, "Optical effects of F-16 Canopy-HUD (Head-Up Display) integration," in *Proc. Dayton Univ. Conf. Aerospace Transparent Mater. and Enclosures*, pp 808–824, 1983.
4. P. Milgram and F. Kishino, "A taxonomy of mixed reality visual displays," *IEICE Trans. Inf. Sys.*, vol. 77, no. 12, pp. 1321–1329, 1994.
5. A. Stone, "How virtual reality is changing military training," *Insights* (Samsung), Jul. 13, 2017, https://insights.samsung.com/2017/07/13/how-virtual-reality-is-changing-military-training/.
6. M. Boyle, "Target's Christmas tree sales aided by augmented-reality feature," *Bloomberg*, Dec. 5, 2018, https://www.bloomberg.com/news/articles/2018-12-05/target-s-christmas-tree-sales-aided-by-augmented-reality-feature.
7. K. Friedrich, "Therapeutic media: Treating PTSD with virtual reality exposure Therapy," *MediaTropes*, vol. 6, no. 1, pp. 86–113, 2016.
8. W. J. Fort, "Virtual reality therapy for phobias at Duke University School of Medicine," *Virtual Visions* (blog), May 6, 2015, https://virtualvisionsblog.wordpress.com/2015/05/06/virtual-reality-therapy-for-phobias-at-duke-university-school-of-medicine-2/.
9. Goldman Sachs Investment Research, "Profiles in innovation: Virtual & augmented reality, understanding the race for the next computing platform," Jan. 13, 2016.
10. Gartner Methodologies, "Gartner Hype Cycle," 2020. https://www.gartner.com/en/research/methodologies/gartner-hype-cycle.
11. Gartner "Hype Cycle for Display and Vision, 2020," Amy Teng et al., Jul. 14, 2020. https://www.gartner.com/document/3987556 (Gartner subscription required).
12. C. Paton, "Virtual reality gamer slips and dies from blood loss after falling on glass table," *Newsweek*, Dec. 23, 2017, https://www.newsweek.com/virtual-reality-gamer-slips-and-dies-blood-loss-after-falling-glass-table-757966.
13. M. Mori (1970), translated by K. MacDorman and N. Kageki, "The uncanny valley," *IEEE Robot. Automat.*, vol. 19, no. 2, pp. 98–100, 2012.
14. M. T. Dennehy, D. W. Nesbitt, and R. A. Sumey, "Real-time three-dimensional graphics display for antiair warfare command and control," *Johns Hopkins APL Tech. Dig.*, vol. 15, no. 2, pp. 110–119, 1994.
15. R. W. Massof, D. L. Rickman, and P. A. Lalle, "Low vision enhancement system," *Johns Hopkins APL Tech. Dig.*, vol. 15, no. 2, pp. 120–125, 1994.
16. W. J. Geckle and R. Raul, "Numerical and experimental simulation of coronary flow characterization using arteriography," *Johns Hopkins APL Tech. Dig.*, vol. 15, no. 2, pp. 126–136, 1994.
17. Q. E. Dolecek, "Computer-generated stereoscopic displays," *Johns Hopkins APL Tech. Dig.*, vol. 15, no. 2, pp. 137–142, 1994.
18. B. W. Hamill, "Immersing people in virtual environments: Perceptual and cognitive considerations," *Johns Hopkins APL Tech. Dig.*, vol. 15, no. 2, pp. 143–153, 1994.
19. W. R. Powell, "Reality, perception, and simulation: A plausible theory," *Johns Hopkins APL Tech. Dig.*, vol. 15, no. 2, pp. 154–163, 1994.

Scott D. Simpkins, Research and Exploratory Development Department, Johns Hopkins University Applied Physics Laboratory, Laurel, MD

Scott D. Simpkins is a Principal Professional Staff member and technical project manager. He has a BS in mechanical engineering, an MS in operations research, and an MS in applied biomedical engineering. He regularly serves as principal investigator for research and development projects and leads integrated product teams that design, develop, and produce prototypes and software applications for specialized requirements. Scott started and led a Gaming, Engineering, and Technology Section at APL and was a member of the development committee for Central Spark, APL's Lab-wide innovation center that was recently expanded to include a dedicated space for exploration of AR and VR technologies. He is an adjunct professor in the Reliability Engineering Graduate Program at the University of Maryland and has served as the chair for professional gaming activities, program chair for gaming application conferences, and an invited speaker for various events, including the Serious Play Conference and APL's XR Symposium. His published work on XR includes contributions to CRC Press, professional society journals, and the *Johns Hopkins APL Technical Digest*. His email address is scott.simpkins@jhuapl.edu.

Patrick D. Allen, Asymmetric Operations Sector, Johns Hopkins University Applied Physics Laboratory, Laurel, MD

Patrick D. Allen is a Principal Professional Staff member and information operations specialist in APL's Asymmetric Operations Sector. He has a BS in physics from Harvey Mudd College, an MS in operations research from the University of California, Berkeley, an MS in strategic studies from the US Army War College, and a PhD in operations research from the Colorado School of Mines. He is a recognized expert in the fields of information operations (IO) and cyber operations, an international consultant in both IO and modeling and simulation (M&S), and a practitioner and instructor in systems analysis and systems engineering. Patrick has 30 years of system design and development, including co-developing a cyber virtual environment in the OpenSIM Multi-User Virtual Environment (MUVE), and is a certified Project Management Professional. He has been awarded one patent and has published two books, five book chapters, and many journal articles. His email address is patrick.allen@jhuapl.edu.

Nicholas W. DeMatt, Information Technology Services Department, Johns Hopkins University Applied Physics Laboratory, Laurel, MD

Nicholas W. DeMatt is a Principal Professional Staff member, chief engineer, and assistant group supervisor of the Applications Group in APL's Information Technology Services Department. He holds a BS in electrical engineering technology from Old Dominion University and an MS in technical management from Johns Hopkins University. He has over 30 years of experience in developing engineering and manufacturing automation processes. For the past 5 years, he has been applying XR technologies to enhance APL's design and fabrication practices and procedures. He is the cofounder of APL's Immersion Central facility and the founder and chair of APL's XR Symposium. He is also a member of the Department of Energy Model-Based Integrated Tools Steering Committee for digital engineering. His email address is nick.dematt@jhuapl.edu.