
# Intelligent Realities For Workers Using Augmented Reality, Virtual Reality and Beyond

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## INTRODUCTION

Through all the industrial revolutions, tools and machines have been central to workers' realities. But it is only recently that large portions of a worker's reality could be digitized with IoT devices and approaches. In 2015, Henning Kagermann, former CEO of SAP AG, argued that this "digitization—the continuing convergence of the real and the virtual worlds will be the main driver of innovation and change in all sectors of our economy." [1] This simple act of creating digital streams produces information that can be expressed in many different ways, on many different types of materials, and in many different systems.[2] This article argues that modern reality presentation technologies are compelling mediums for the expression of digital IoT streams.

Such reality presentation technologies include the eXtended Reality (XR) family of technologies [3] -- Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR) – as well as more mature and accepted technologies such as smart phones, tablets, and PC flat screens. When combined with IoT, analytics and artificial intelligence, applications can be created that can aid workers by making their realities more intelligent.

An intelligent reality is defined here as a technologically enhanced reality that aids human cognitive performance and judgement. As compared to the base reality, an intelligent reality can have much greater dimensionality, reduced occlusion, transcendence of distance, better guidance and improved communication with other actors. This definition deliberately does not exclude non-physical realities in domains such as finance and cybersecurity, but the focus of this article is on intelligent realities based on physical realities and fed by IoT.

Consider a technician looking at a machine while wearing an AR Head Mounted Display (HMD) can see both the service history and prediction of future failures. This gives the worker a view on the fourth dimension of time, both backwards and forwards. Instead of having to take the machine apart, the worker can see an IoT driven mixed reality rendering projected on the outside casing. By just glancing away from the machine, he can see a virtual rendering of the operations of the same type of machine at a distant location. Then, he can interface with both artificial and human remote experts about next steps, which could include the expert

[1]H Kagermann, "Change Through Digitization-Value Creation in the Age of Industry 4.0," Management of Permanent Change, p 23, 2015. Available: https://www.researchgate.net/publication/284761944_Change_Through_Digitization-Value_Creation_in_the_Age_of_Industry_40

[2] J. Brennen, D. Kreiss, "Digitization," The International Encyclopedia of Communication Theory and Philosophy, p 557, 2016 .

[3] C. Fink, "War of AR/VR?MR/XR Words," Forbes, Oct 2017. Availablehttps://www.forbes.com/sites/charliefink/2017/10/20/war-of-arvrmrxr-words/#2d75b71e8d07

driving virtual overlays of his view. As he decides on next steps, he can communicate with appropriate management systems through that same HMD without having to pull out a phone or laptop. As a wearable computer, the HMD brings distant resources in to the worker's operational reality.

An intelligent reality may be proximate to a worker, like a machine on a factory floor. Or that factory might be half way around the world and understood by the user through 3D modeling of the factory. AR or VR headsets may be involved, but do not have to be – smart phone screens or flat screens on a desktop may be a better option. The worker may be mobile and use an AR head mounted display or smart phone, or the worker may be stationed in a command center at the company headquarters. They may be observing a reality in real time, or they may be performing data-driven review of an event that occurred in the past. In all cases, though, the context dominates – both visually and in the design of the presentation.

Intelligent reality can be achieved today with off-the-shelf technologies spanning IoT, analytics, XR technologies, and more traditional user interface technologies. This new paradigm is introduced here to help decision makers and architects navigate the expansive terrain of technologies that can enable intelligent realities for workers. First, the XR space is overviewed along with more traditional mobile and desktop flat screens. This leads to the consideration of intelligent reality architecture and the development of intelligent reality applications. From there, specific use cases are proposed that exercise combinations of reality presentation technologies, IoT and AI.

## THE REALITY-VIRTUALITY CONTINUUM AND MODERN EXTENDED REALITY

In 1995, Paul Milgram et al published a paper "A Taxonomy of Mixed Reality Visual Displays", which introduced the Reality-Virtuality Continuum.[4] This paper remains useful for discussing the current state of XR as well as considering the role of mobile and stationary flat screens. Figure 1 illustrates the continuum between purely physical reality and purely virtual.

[4] P. Milgram et al., "Augmented Reality: A class of displays on the reality-virtuality continuum," Proceedings Volume 2351, Telemanipulator and Telepresence Technologies, Dec 1995. Available: http://etclab.mie.utoronto.ca/publication/1994/Milgram_Takemura_SPIE1994.pdf


*Figure 1: Reality-Virtuality Continuum (From Wikipedia)*

From left to right, the user moves from a normal view of physical surroundings to a completely digital view. In between the extremes is Mixed Reality (MR) -- the mixing of the physical reality with one or more digital realities. MR assumes an AR device that is capable of stereoscopic rendering of dynamic 3D scenes on top of a physical view of the world.

On the far right, a virtual environment is completely digital, but not necessarily completely immersive. The authors include both the completely immersive experience of a VR Head Mounted Display (HMD) as well as large flat screens not worn by the user. Both VR HMDs and virtual environments rendered on flat screens can provide a user with a dynamic, real-time 3D rendering of a remote or abstract 3D reality.

Just as the authors did not limit virtual environment presentation to HMDs, their definition of AR does not exclude mobile flat screens. In 1995, they lacked the terms "smart phone" and "tablet," but they described "monitor based (non-immersive) video displays – i.e. 'window-on-the-world' (WoW) displays – upon which computer generated images are electronically or digitally overlaid."

**The Modern Reality-Virtuality Landscape**

Figure 2 illustrates the Reality-Virtuality Continuum with commercially available products. The lower quadrants are traditional flat screens while the upper quadrants contain the newer and less established HMDs.

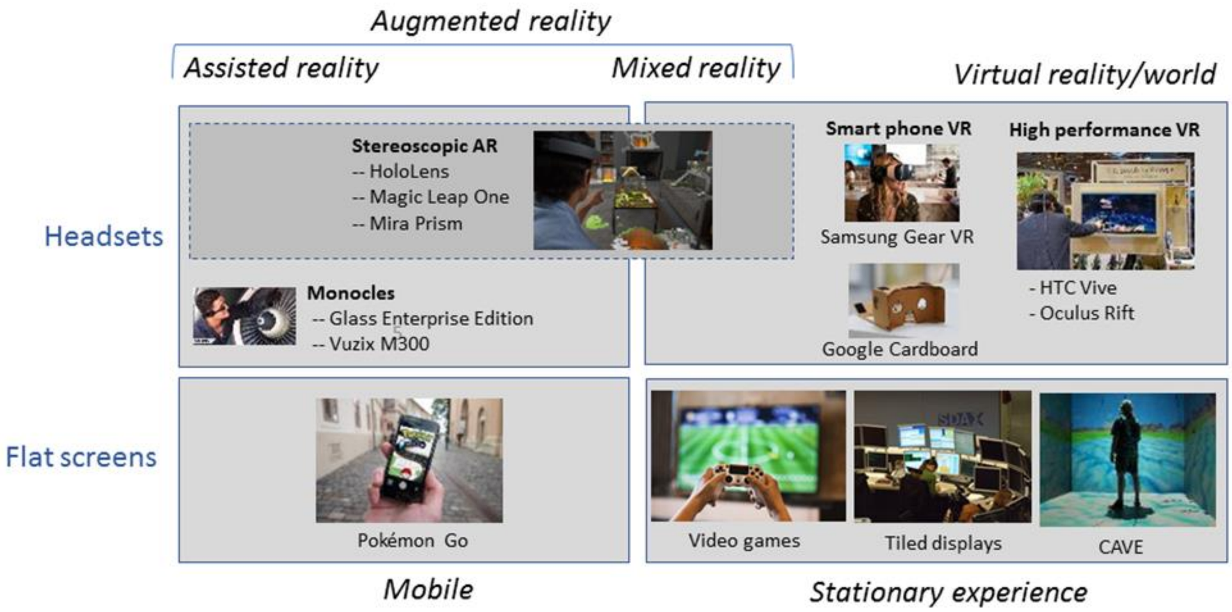


*Figure 2: Devices on the Reality-Virtuality Continuum[5]*

The quadrants represent different use cases and approaches:

- Lower left: smart phone and tablet AR. Smart phones and tablets are so pervasive that the incremental hardware cost is often zero. But they are not heads-up and hands-free.
- Lower right: flat screen virtual worlds (or VR for the flat screen). This includes virtual worlds on flat screens, tiled displays and Computer Assisted Virtual Environments (CAVEs).
- Upper right: virtual reality for HMDs. The market supports different VR devices with different resolution, field-of-view, and processing power. Tethered HMDs connected to powerful PCs, including HMDS from Oculus™, HTC™, Lenovo™ and PiMax™, are the most capable. Less capable but also less expensive and sometimes more convenient are smart phone approaches such as Google® Cardboard™ and Samsung® Gear VR™.
- Upper left: AR HMDs. With AR, the design fragmentation is the greatest. There are three basic design categories:
  - Stereoscopic headsets. Larger and compatible with prescription glasses. Microsoft® HoloLens™ is a headset. Mira Prism™ is a headset that utilizes a smartphone.
  - Stereoscopic smart glasses. Smaller but users may need to procure prescription lenses for

[5] Attribution for embedded images, starting clockwise from upper left: Vuzix, Microsoft Sweden, Nan Palmero, Google, Jean-Pierre Dalbéra, Dave Pape, Wikimedia user Dontworry, EVG photos, pixabay.com

the device. Magic Leap One exhibits the smart glasses form factor.

- Monocle devices. A small screen in front of one eye. They tend to be compatible with prescription glasses. These devices focus on "assisted reality" – the display of flat content such as charts, videos, and text to the side of a person's view.[6]

As illustrated with the dotted box around stereoscopic AR, these devices can handle assisted reality use cases and can satisfy some use cases in the VR space that don't require full immersion. One example of the latter is examining a virtual 3D model of a building at arm's length.

**Efficacy of XR in Commercial Settings**

Most any new technology both generates hype and begs questions of its usefulness. In the case of XR, there have been several encouraging studies about their efficacy:

- In its November-December 2017 issue, Harvard Business Review published an article "Why Every Organization Needs an Augmented Reality Strategy."[7] The article also discussed commercial use of VR. In their research, the authors found various positive outcomes, including:
  - DHL® and Intel© saw AR related warehouse picking productivity gains of 25% and 29% respectively, with Intel seeing error rates falling to near zero.
  - Newport News Shipbuilding® used AR and reduced inspection time by 96% because the final design could be superimposed on a ship.
  - Lee Company®, which sells and services building systems, calculated a return of $20 on every dollar it has invested in AR.
- An AR experiment by Dr. Steven J. Henderson and Dr. Steven Feiner of Columbia University in 2009 found that a "prototype AR application allowed a population of mechanics to locate individual tasks in a maintenance sequence more quickly than when using an improved version of currently employed methods."[8]
- In the paper "Virtual Reality and Augmented Reality as a Training Tool

[6] S. Crucius, "What Is Assisted Reality and How Does It Relate to Augmented Reality?" Wearable Technologies, June 2018. [online] Available: https://www.wearable-technologies.com/2018/06/what-is-assisted-reality-and-how-does-it-relate-to-augmented-reality/

[7] M. Porter and J. Heppelmann, "Why Every Organization Needs an Augmented Reality Strategy," Harvard Business Review, Nov-Dec 2017. Available: https://hbr.org/2017/11/a-managers-guide-to-augmented-reality

[8] S. Henderson and S. Feiner, "Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret," 2009 8th IEEE International Symposium on Mixed and Augmented Reality, Oct 2014. Available: https://ieeexplore.ieee.org/document/5336486

for Assembly Tasks" from The School of Manufacturing and Mechanical Engineering at The University of Birmingham, the authors investigated if AR and VR offered potential for training of manual skills.[9] They compared AR and VR training methods to the use of conventional 2D engineering drawings and found that AR and VR approaches resulted in significantly reduced task completion times.

- In the 2015 paper "Augmented Reality as a Tool for Production and Quality Monitoring," the authors tested use of an AR system rendering information from Computer Aided Quality (CAQ) software and compared it to scenarios using only CAQ software and using no software.[10] AR integrated with CAQ was found to be the fastest approach.

## INTELLIGENT REALITY ARCHITECTURE

An architecture for an intelligent reality should be centered on aiding a worker's cognition and performance. For workers in an IoT-enabled reality, the cornerstone of an intelligent reality architecture is the integration and sense-making of raw IoT data. This is discussed first in this section. With the data and analytical foundations in place, an architectural view of the reality presentation technologies is presented for making the best tactical last-mile UI decisions for rendering to the workers.

**IoT Data Pipeline**

For real time sense making of an IoT asset, a streaming analytics engine is necessary.[11] A streaming analytics engine, like SAS® Event Stream Processing, analyzes data streams in motion as the atomic events of the stream pass by. In addition to applying analytical methods, it can also provide inferences derived from machine learning models as well as contribute to the training of such models.

In addition to immediate presentation, analyzed data streams can also be transferred to data stores for further analysis and later presentation. While the big data problems related to IoT described by Belli et al in "A Scalable Big Stream Cloud Architecture for the Internet of Things" need

[9] A. Boud et al., "Virtual Reality and Augmented Reality as a Training Tool for Assembly Tasks," 1999 IEEE International Conference on Information Visualization, Jul 1999. Available: https://pdfs.semanticscholar.org/a563/afc2156eb7285dc67c1c5be7dd3787f0db04.pdf

[10] D. Segovia et al., "Augmented Reality as a Tool for Production and Quality Monitoring," Procedia Computer Science 75:291-300, Dec 2015. Available: https://core.ac.uk/download/pdf/81959814.pdf

[11] B. Klenz, "How to Use Streaming Analytics to Create a Real-Time Digital Twin," SAS Global Forum 2018, Mar 2018. Available: https://www.sas.com/content/dam/SAS/support/en/sas-global-forum-proceedings/2018/2004-2018.pdf

to be addressed[12], they are not unique to reality applications. Reality applications can be networked and fit in with a traditional query-and-reporting client-server architecture. As observed in "Immersive Analytics: Building Virtual Data Worlds for Collaborative Decision Support", traditional 2D data visualization can work across the reality-virtuality continuum.[13]

## General Model of Device and Reality Interaction

On the UI front, intelligent reality has been enabled by wearable and portable computers, including XR HMDs and smart phones, and high-performance graphics that can faithfully render realities. While HMDs represent an important shift in computing, they are still wearables that may not be acceptable to many users and use cases. The following architectural view attempts to de-emphasize the importance of HMDs in reality intelligence architecture.

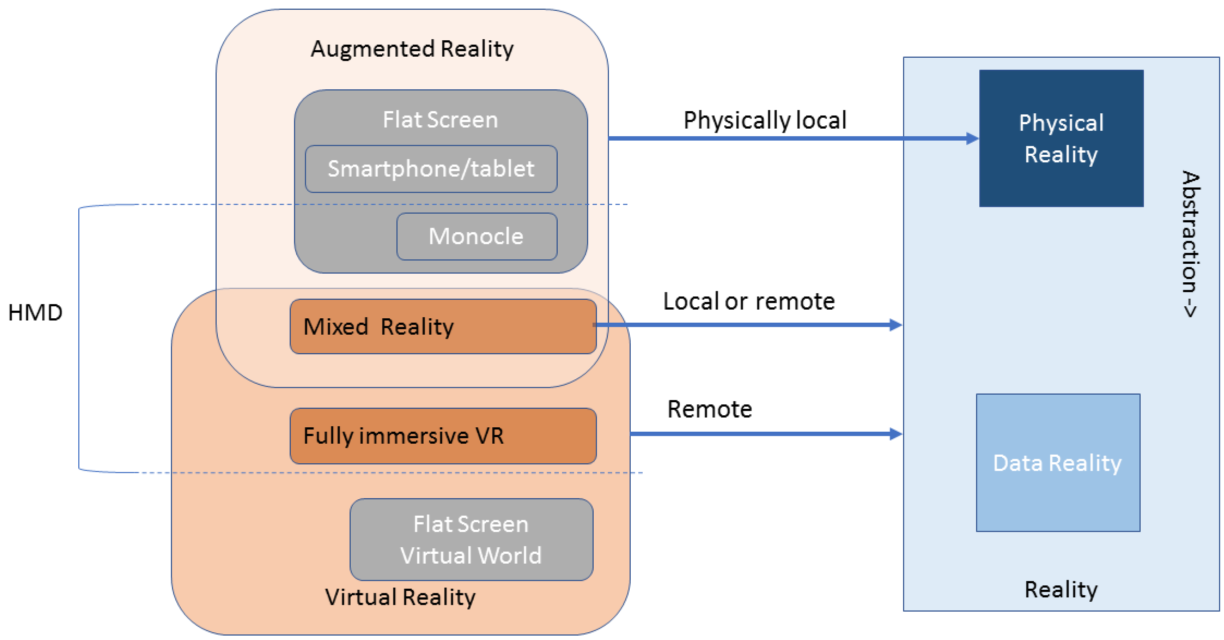


*Figure 3: Device and reality interaction view*

[12] L Belli et al., "A Scalable Big Stream Cloud Architecture for the Internet of Things," International Journal of Systems and Service-Oriented Engineering, 5(4), 26-53, October-December 2015. http://www.tlc.unipr.it/ferrari/Publications/Journals/BeCiDaFeMeMoPi_IJSSOE15.pdf

[13] R. Hackathorn and T. Margolis, "Immersive Analytics: Building Virtual Data Worlds for Collaborative Decision Support," IEEE VR2016 Workshop, March 2016. Available: http://www.immersiveanalytics.com/wp-content/uploads/2016/05/VR2016-IA-HackathornMargolis-20160322.pdf

Starting on the right, in Figure 3, is the general concept of reality drawn to include both physical and abstract realities. A machine is a physical reality, while the supply chain that created that machine is an abstract reality derived from data – a data reality. At the most abstract, data realities can be completely de-coupled from any physical reality. For example, large volumes of live streaming data from a commodities market could be used to form a data reality which a user could explore in VR.

The left side combines the three main concepts of augmented reality, mixed reality and virtual reality. Due to the see-through nature of AR devices, proximate physical reality is always part of an AR experience. But an implementor may choose to use a mixed reality device to satisfy a use case that has nothing to do with the proximate physical reality – for example, rendering a 3D model of a supply chain independently. They may make this choice because users prefer mixed reality over virtual reality because being aware of physical surroundings is more comfortable. Thus, mixed reality could be effectively remote or local.

VR tends to mean a fully immersive experience with an HMD. But a VR asset could be rendered in MR or on a flat screen. This article has not taken on the trouble of constantly restating that a virtualization of reality can be rendered on an AR stereoscopic HMD, a flat screen, or a fully immersive VR HMD. Unless specifically qualified, the term VR takes the meaning of a virtualization of a reality and does not assume the target device.

### The Base Software Layers Across the Reality-Virtuality Continuum

Reality applications of any type, including games as well as industrial applications, rest atop lower level software layers that have emerged to solve the different problems described here:

### Gaming Engines for Dynamic and Interactive 3D Models

Many developers use gaming engines like Unity and Unreal to develop these models as well as output the executable application.[14] These development tools can output applications across many platforms, including AR and VR HMDs, smart phones, tablets and PCs, which can communicate over networks with servers and other applications. Amazon Sumerian is a web-based alternative that gives developers an easier but more limited alternative to gaming engines. [15]

The gaming engines can import 3D models from other sources, including tools such as Autodesk® Maya™ that are focused on original 3D content creation by artists as well

[14] W. Wise, "How to pick the right authoring tools for VR and AR," O'Reilly On Our Radar, October 2017. Available: https://www.oreilly.com/ideas/how-to-pick-the-right-authoring-tools-for-vr-and-ar

[15] R. Marvin, "Inside Sumerian, Amazon's Big Bet on Augmented and Virtual Reality," PC Magazine, April 2018. Available: https://www.pcmag.com/feature/360323/inside-sumerian-amazon-s-big-bet-on-augmented-and-virtual-re

as tools that can import existing CAD drawings. In addition, AI can create 3D content. Booz Allen® has demonstrated the use of generative adversarial networks to greatly reduce the time and expense of content creation for simulation.[16]

### World Knowledge with Computer Vision

In Milgram's paper cited earlier, the authors identified the dimension of Extent of World Knowledge, with the end points of an unmodelled world and a completely modelled world. For AR applications, an application needs to at least partially model the world, which the authors divided in to knowing what an object in the view is and where it is in the view.

For enterprise reality applications, the identity of an object matters. For example, a fleet manager standing in front of a bus needs to know exactly what bus it is, not just that it is a bus. Object identity can be achieved by reading bar codes, QR codes, text or other uniquely identifying marks.

Once an asset is identified, natural feature tracking and object recognition can be employed to recognize component parts. For example, the fleet manager can first glance at the license plate of the bus and then see the correct data-driven overlays for that bus as they move around because computer vision is identifying parts of the bus, such as the tires, engine, etc.

### Mixing realities

An additional type of SDK is focused on the mixing of digital and physical realities. To properly place a digital reality in to physical reality, the surfaces in the physical world and lighting need to be understood. ARCore™ from Apple® and ARKit™ from Google solve these problems for iOS and Android, respectively.[17]

### Intelligent Reality and AI

The various technologies under the AI umbrella are quickly becoming just additional tools in the developer toolbox. This is certainly true in the XR space. For example, when the original Microsoft HoloLens released in 2016, it came with both voice recognition and computer vision available to application developers. [18]

But there is a lot more room for AI in the intelligent reality space than these baked-in features. The following sections look at several areas where AI can provide value to workers' perceptions of their realities.

### Overcoming XR UI Limitations

Just as the transition from desktop to smart phone apps required new approaches, reality apps introduce their own UI

[16] N. Mehta et al., "The Role of AI in a VR World," GPU Technology Conference, October 2018. Available: http://on-demand.gputechconf.com/gtcdc/2018/pdf/dc8209-the-role-of-ai-in-a-vr-world-presented%20by-booz-allen-hamilton.pdf

[17] M. Giles, "AR still doesn't have a killer app, but Google's ARCore is here to help," MIT Technology Review, Feb 2018. Available: https://www.technologyreview.com/s/610336/ar-still-doesnt-have-a-killer-app-but-googles-arcore-is-here-to-help/

[18] D. Bohn and T. Warren, "Up close with the HoloLens, Microsoft's most intriguing product in years," The Verge, January, 2015 [online]. Available: https://www.theverge.com/2015/1/21/7868251/microsoft-hololens-hologram-hands-on-experience

constraints. Both VR and AR reality analytics apps must deal with the basic problem of putting context first. If users are going to gain value from having their analytics in context, then the analytics cannot overly obscure the context. In VR, that means that a 3D model of a factory should be visually dominant if it is to properly contextualize a chart about some aspect of the factory's operations.

As UI space is at a premium, it becomes important to use that space wisely. The challenge is to give the user the best information for their role at that point of time and for their current location. AI can help solve that problem. Rather than forcing the worker in to a data exploration UI paradigm which would require many selection actions, AI can make content selections on behalf of the worker.

### Artificial Remote Experts

In the popular remote expert use case for AR[19], the remote expert could be human or artificial. For example, a field technician wears an AR HMD and a human remote expert can see what the technician is seeing through the head-mounted camera. The remote expert could also access equipment history and metrics.

An artificial expert could also carry this burden or work in concert with a human expert. The AI chatbot practices[20] seen at call centers can be brought to bear. Just as chatbots replace first level call center representatives, they can alleviate remote experts from first level work. Then, a single remote expert can cover more junior workers and focus on tougher problems.

### Digital Twin Overlay

The Industrial Internet Consortium defines a digital twin as "a digital representation of an entity, including attributes and behaviors, sufficient to meet the requirements of a set of use cases." [21] It is not only data about a physical asset, like its service history. A good digital twin takes the information about the design, production and operational life of the asset and virtualizes it in to a digital asset that can be tested and modified in ways that you would never treat an operating physical asset. Instead of a single expensive crash test of a car, you could perform millions of crashes virtually. Rather than a couple of turns around a test track, a car could be virtually driven for millions of miles across multiple tests with different service histories. Such tests could then be used to feed machine learning neural nets which are then queried when servicing the real asset.

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[19] E. Hadar et al., "Hybrid remote expert - an emerging pattern of industrial remote support," CAiSE Forum, 29th International Conference on Advanced Information System Engineering, Essen, Germany, June 2017. Available: http://ceur-ws.org/Vol-1848/CAiSE2017_Forum_Paper5.pdf

[20] K. Nimavat and T. Champaneria, "Chatbots: An Overview. Types Architecture, Tools and Future Possibilities," International Journal for Scientific Research & Development, October 2017 https://www.researchgate.net/publication/320307269_Chatbots_An_overview_Types_Architecture_Tools_and_Future_Possibilities

[21] Q1 Digital Twin Interoperability TG Meeting Minutes, Feb 2019, Available: https://workspace.iiconsortium.org/higherlogic/ws/groups/interop-tg/download/25418/latest

With an intelligent reality application, the digital twin can be overlaid directly on the physical twin. When a bus rolls in to the garage, a fleet manager can view important output from the bus's digital twin as an AR overlay. A simple example is showing an alert because the bus is overdue an oil change. But the real power of the digital twin would come from more nuanced cases that aren't simple violations of established single-dimensional rules. Perhaps the bus is within the accepted ranges across several aspects of maintenance, but the digital twin sees that a combination of near violations greatly increases the risk of a mission-critical failure. The AR device can communicate to the manager who can then take appropriate action.

**Feeding AI from XR Devices**

When a factory deploys a thousand AR HMDs to workers, they are also deploying at least a thousand head mounted cameras. Those cameras are well-positioned to provide a rich set of video content. Such content can be piped through computer vision and then on to machine learning and other analytical models. In addition to video from the cameras, HMDs can transmit precise information about the position and orientation of the head of the wearer.

For manufacturing, an AR-enabled workplace could generate machine learning models that are trained based on head position, gaze, placement of components in the workspace, and quality outcomes. Once trained, such a model could detect small movements and practices that lead to poor quality outcomes and suggest better practices immediately through the HMD. Such learnings can be deployed back in to workers' intelligent realities.

While VR doesn't offer the same connection to the physical world, a VR HMD can also communicate position and orientation of the workers' heads. Eye tracking is also making it in to XR products, including HTC Vive Pro Eye™ and Microsoft HoloLens2. Such information can be used to improve the simulation as well as strengthen the understanding of how humans would react in the physical analogue of the virtual environment.

## EXAMPLE USE CASES FOR INTELLIGENT REALITY

This section considers three use cases for reality analytics along with architectural solutions to their problems.

**Augmented Reality Chess Coach**

In this first use case, the work is developing Science, Technology, Engineering, and Mathematics (STEM) skills in young children, and the workers are parent volunteers that want to share the STEM benefits of chess with elementary schools.

Chess is known to aid the development of STEM skills for students as young as elementary school and elementary school chess clubs can provide a venue for youth chess play.[22] It should be possible to use computer vision to interpret and analyze a chess position on a physical board. This capability could be packaged in an app that aids the parent volunteer in both ensuring legal chess play and providing chess coaching and knowledge.

But the economics of youth chess clubs are daunting. Chess equipment is cheap, with a set that will last twenty years costing cents per player per year. While there are sensor-laden boards that can stream moves across the Internet in the IoT style where the "things" are the chess pieces, such as the DGT smart board, they are much too expensive for a typical club. Computer vision is the better economic choice over a sensor approach.

Either a smart phone or an AR head set is a reasonable choice to host the app. But headsets are both expensive and new to most potential parent volunteers. Smart phones, on the other hand, are already in the pockets of most parents.

The computer vision problem breaks in to four parts – finding the board in the image, creating a 3D coordinate space that finds all 64 squares, recognizing the pieces in legal play on the board, and then correctly placing the pieces on the squares. Then the position can be stated in the standardized Forsyth-Edwards Notation (FEN) and passed to a chess analysis engine. The engine can then check if the position is legal, checkmate, draw or stalemate and communicate that to the volunteer. It can also analyze the position and provide coaching info. The architecture is illustrated in Figure 4.

[22] M. Thomas, "Scholastic Chess Clubs: 10 Reasons Why," SAS Voices, Aug 2014 [online]. Available: https://blogs.sas.com/content/sascom/2014/08/29/scholastic-chess-clubs-10-reasons-why/

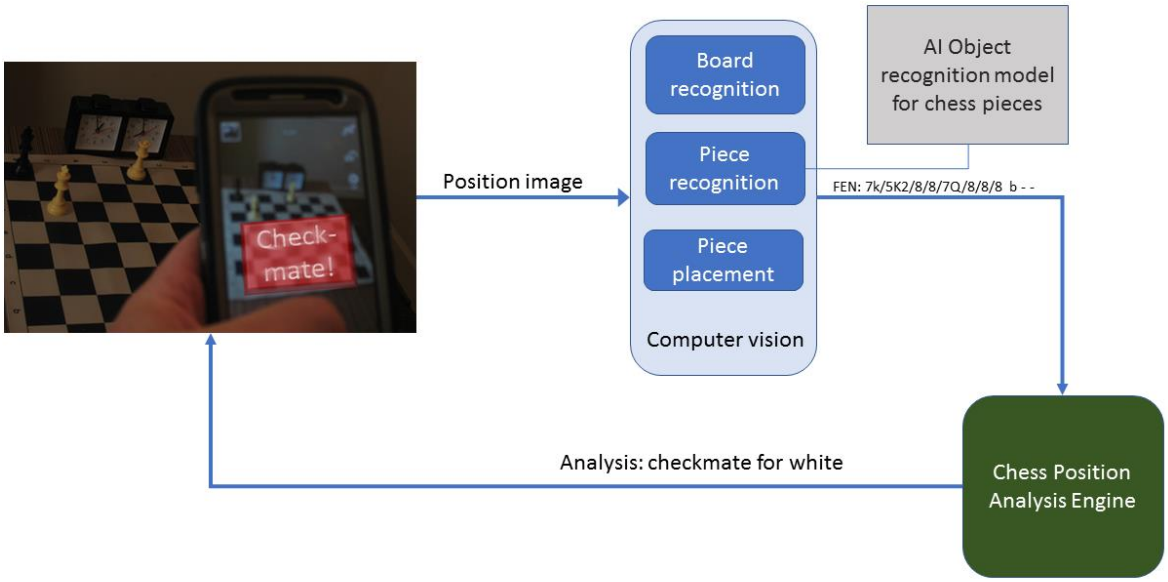


*Figure 4: Architecture for Augmented Reality Chess Coach*

While the output is still analytical in nature, traditional charts would not be prevalent. If a pair of third graders raise their hands to ask if they have arrived at stalemate, then the single word ‘stalemate’ or ‘checkmate’ is all the output the parent volunteer needs. Even coaching tips, such as “count the number of attackers and defenders on the e4 square” are best expressed textually rather than visually. It is not always the case that reality analytics is visual.

The same architecture could be adapted for other usages by replacing the chess position analysis engine with another type of analytical engine. This engine could be built with machine learning or other techniques.

**Smart Facility Maintenance with a Digital Twin and AI**

As sensor-laden facilities become smarter, digital twins can be developed to aid in the care of smart facilities. Ideally, a digital twin for a facility would include operational models of machine behavior provided by manufacturers. When manufacturers deploy machines that “phone home” with their operational data they can build a strong digital twin with machine learning based on many cases of production usage. Then, an individual facility can compose a digital twin by combining those digital twins into a composite digital twin for the entire facility. The facility digital twin would also absorb building plans, such as CAD drawings, and encapsulate all of it in to a gaming engine project that reaches out to the included models. The gaming engine app front-ends

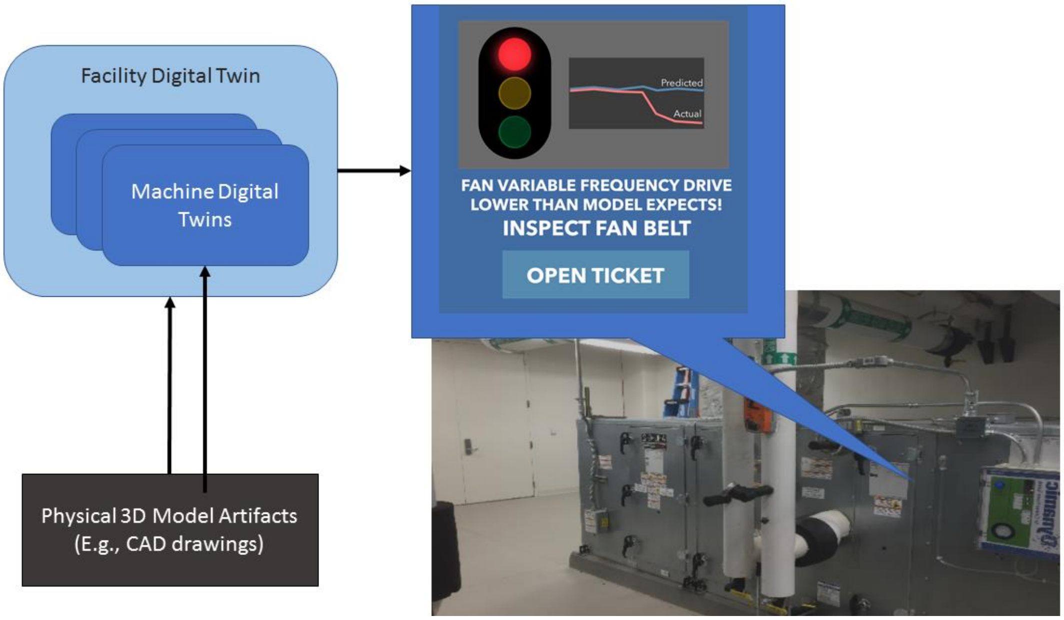


*Figure 5: XR and Digital Twins*

the digital twin for human consumption over AR or VR.

For performing the maintenance work, the digital twin provides a powerful twist on the typical remote expert use case, as discussed earlier. An AI expert could either completely replace a human expert, or, more likely, significantly aid the human expert.

For the field technician, a handheld computer such as a smart phone or tablet with an AR app remains a valid choice, but an HMD device is a much more plausible fit than in the previous example. For many field technicians, being heads-up and hands-free is advantageous enough to justify the cost of an AR HMD. An HVAC technician, for example, can enter a machine room and fix an air handler without ever consulting a manual or occupying their hands with a tablet or smart phone and without ever possessing a check list beforehand. Before leaving, the HMD could even direct them to address several other issues so that they would not have to return to the room for a while.

**Smart City Emergency Response**

Cities are getting smart, thanks to IoT, but all the technology increases the attack surface available to wrongdoers. Traffic accidents can be caused by manipulating signals or even directly hacking vehicles. Building systems, including locks and ventilation, could also be coerced into malignant service.

When responding to IoT based cyberattacks and other emergencies, a city can employ both AR and VR in conjunction with streaming analytics, as illustrated in Figure 6.

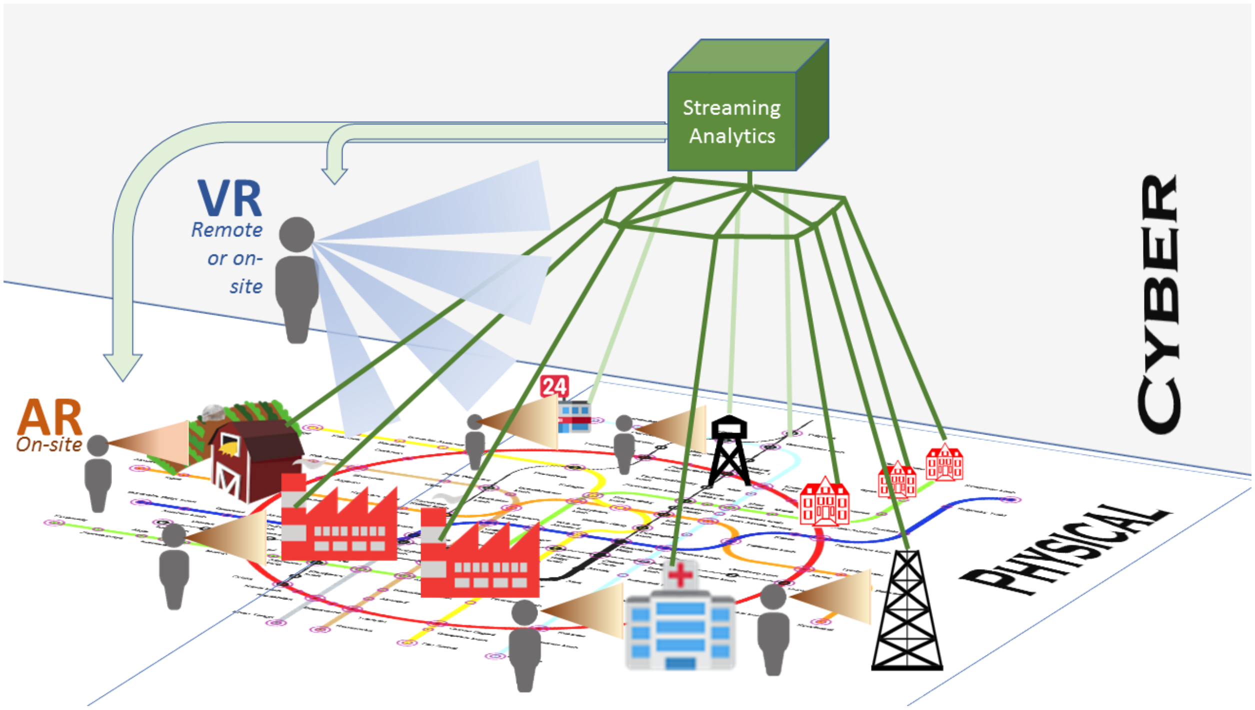


*Figure 6: Smart city emergency response with XR and streaming analytics*

In an instrumented and digital twinned city, both AR and VR techniques can be useful. At street level, first responders and other field workers can use AR to understand the city's infrastructure and emerging conditions. Either smart phone or a HMD could work, though the heads-up hands-free capabilities of HMDs would be very appealing in this case. Imagine a fireman going into a building that has hazardous chemicals and active gas lines. Fumbling for a smart phone with heavy gloves is far from ideal. But having a rugged HMD as part of the outfit could do much to keep the fireman safe and effective. Still, smart phone and even tablet usages of AR could be useful for those that are not so directly hands-on and in the literal line of fire. For example, a city worker who isn't a front line professional could be deployed in a crisis response and be effective after a quick app download to the phone. That would be far easier and less costly than having excess AR HMDs available.

Remote analysts can utilize VR techniques both to understand a city-wide crisis holistically as well as assist workers on the ground at a specific site. While a first responder is always anchored to a physical location and can only acquire different perspectives at the speed of available locomotion, a remote analyst can easily teleport about a virtualization of the same scene and see through buildings. They can also quickly slice their time between different sites that may be different parts of the same crisis. A VR HMD is a good option for this work, but analysts could also use desktop flat screens towards the same purpose.

Tying together the field and remote workers is streaming analytics and AI. Both field and remote devices can be fed in real-time by the same engine over standard network protocols. Just as two different users of the same web site can have a consistent view of live data, a proximate first responder and a remote analyst can share the same view. Through standard telephone voice technology, they can stay in sync and communicate around the same data. The streaming analytics engine can tie in to machine learning inference just as in the previous example.

## CONCLUSIONS

This article introduced and explored the notion of intelligent reality -- an underlying conceptual transition towards the contextualization of IoT analytics by utilizing gaming engines, AI and computer vision software. The combination of XR, AI and IoT should lead to greater penetration of data science into the world of work. When these technologies operationalize analytics, cost savings can be realized across an enterprise.

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