Practical Overview of Augmented Reality (AR) for Worker Development, Safety and Skills Retention

Author

Eric Almquist
Business Development Engineer, Star Tool, Chicago Heights, Ill., USA
ealmquist@startoolanddie.com

Global industry, including steel, faces parallel crises of worsening shortage of skilled workers with accelerated retirement rates of skilled trades holding critical knowledge. Add to these challenges the evolution of communication preferences from written words to digital imagery. State-of-the-art augmented reality (AR) systems are proven to ease these challenges. This paper will provide data of the challenges along with a practical overview of current AR technology, evidence of how AR has and can ease challenges of skills, available time, retaining knowledge, safety and bridging generational challenges, amongst others.

The evolution of technology has impacted our lives at home and work. The pace of technology advancements has accelerated with some key milestones marking periods. The world has entered one of these periods, commonly called "Industry 4.0," referring to the fourth Industrial Revolution (Fig. 1).

Augmented reality, or AR for short, is a specific technology considered to be the human-machine interface (HMI) of Industry 4.0. Futurists and digital device companies envision people using AR to interact with their digital devices in ways most have seen only in movies; seeing a layer of digital information projected over reality, augmenting it — hence the name. AR may seem like science fiction to those who have not experienced it, but since 2016 real AR tools for industry began appearing. By 2017, software and hardware had emerged to become a real business tool for manufacturing to ease real and worsening challenges.

AR will revolutionize frontline worker jobs over the next decade, just as the desktop PC has revolutionized office worker jobs since the 1980s. Of particular interest is AR's ability to capture and digitally record the workflows and practices of experienced subject matter experts (SMEs) tradespeople and, from there, to enable less-experienced workers access and use those expert workflows. AR can help optimize safe practices by providing easy access to detailed but cognitively connected safety training, lockout/tagout/try-out procedures, and opportunities for training with equipment. AR

Figure 1

Industry 4.0, or smart factory; manufacturing within a collection of digitally interconnected technologies. Augmented reality (AR) is the human-machine interface (HMI) of Industry 4.0.

even allows practicing these workflows without having the actual equipment, but projecting 3D model holograms of the equipment as practice surrogates.

Discussion

What Is Augmented Reality? AR is one technological pillar supporting Industry 4.0, the fourth subrevolution of the Industrial Revolution. AR is the human-machine interface (HMI) of Industry 4.0 and will become the standard interface between humans and their digital devices at work, home and in between. Most consumer mobile phones, tablets and portable PCs have already incorporated AR-capable software modules within the operating system code (e.g., Apple's ARKit, Android's ARCore, etc.). Furthermore, many consumer electronic device original equipment manufacturers (OEMs) are developing wearable devices, such as spectacles, as the user interface. The new devices are far different and superior to the awkward Google Glass product many may recall from 2013/2014 which, in fact, was not a formal AR device, but merely a more convenient input-output/display device.

Proper AR technology displays a "layer" of digital information over the user's view of reality, "mixing" the digital layer with reality as if to appear part of reality (Fig. 2). This digitally produced, synthetic digital layer augments the user's view of reality. AR is primarily a visual tool, but audio often enhances the experience.

AR is revolutionizing the labor workspace just as the PC has revolutionized the office workspace since the 1980s. Frontline workers using AR are empowered with information technology (IT) pertinent to their job. Most industrial workflows (e.g., tasks, jobs, SOPs, etc.) require specific procedures not intuitively obvious and require training. Even with proper training, many tasks are so complex, done so infrequently or have such critically bad consequences if done improperly that the worker must reference manuals, ask the most experienced person for advice, or even hire specialized contractors to complete the task. Even then, it's typical to have a multitude of details to succeed by chance for a safe and positive outcome. Even the most experienced and conscientious workers are imperfect: they may experience memory errors, lapses in concentration, or may be pulled away from job by a coworker needing help, etc. Any of these can cause errors and AR can help mitigate. AR is a tool to help a worker of any skill level. However, it has proven tremendously powerful to enhance the competency of less-experienced workers. More on this later.

As with any developing and competitive technology space, there are a wide array of capabilities with AR. There are many poorly executed versions of AR available that are understandably disparaged as "tech toys" and there are a few real tool versions of AR hardware and software available. This paper cites capabilities and use-case examples from an especially capable version of AR software called MANIFEST, which is continuously evolving to meet the needs of its early adopters within industry and the military. [Important: AR system capabilities vary significantly. AR systems are not equal. Each is different; sometimes slightly but often drastically. This paper strives to be a technical, non-commercial resource but it is important for the reader to understand the specific information, and examples shown in this paper are produced from MANIFEST AR.]

Figure 2

A first-person, user's view of AR through a stereoscopic AR-enabled head-mounted display i.e., "AR goggles."

Some Labor Challenges and Some Solutions Offered by AR — Manufacturers are facing some great challenges related to workers. Three key challenges for every company are:

- Worker knowledge: Retaining and sharing.
- Skilled labor: Retaining and developing.
- Worker knowledge: Transferring between generations.

1 of 3 — Worker Knowledge: Retaining and Sharing: Tribal knowledge is a convenient, and scalable, term encapsulating the collection of operational workflows held within a domain of people. Domain is the scaler; it can mean the entire company, a department of that company, and so on, downward into very specific areas and jobs within the company. Tribal knowledge is any information not intuitively obvious to outsiders and pertaining to processes residing only within the experience of the people within the particular domain.

An example of tribal knowledge within the steel industry might be the best way to set up a rolling mill or other complex, multi-variable equipment for a particular product and conditions. Imagine the scenario of a very experienced operator from CRM#1 being asked to help at CRM#2 in the same capacity. Even though this very experienced operator from CRM#1 is a subject matter expert, chances are likely their tribal knowledge from CRM#1 won't directly translate to CRM#2. Despite their tremendous experience of reliably producing high-yield, prime material on CRM#1, their initial results on CRM#2 may likely be poor because they lack tribal knowledge specific to CRM#2.

Other examples of tribal knowledge within a steel plant might have nothing to do with manufacturing operations. Someone else knows how to optimize expedited shipping of a coil to an important customer, or how to prepare the conference room for a particular meeting, or anything else to optimize the outcome within a specific set of circumstances. Some of those circumstantial factors can be company/management culture, societal culture, team demographics, department status within the plant, availability of tools, equipment conditions or changes, etc. There are infinite combinations. With these countless options, employees obtain and hold the critically important tribal knowledge with procedural workflows which are not obvious or even intuitive to outsiders. It is safe to assume anyone of any level of expertise from outside the group will need access to the tribal knowledge workflows with some levels of training.

Consider the following relation:

$$\text{Tribal Knowledge} = \Sigma\ (\text{Workflow Art})$$

Tribal knowledge is the collection of procedures called workflow art: each a precise set of procedural steps necessary to produce a favorable outcome. Often these workflows have been iterated several times to accommodate the circumstantial factors explained above — conceivably to a point where the OEM maintenance manuals no longer apply. Perhaps the optimal, or only, way to learn workflows is to work with and learn from the most experienced tradesperson.

Workflow art has levels of refinement. An analogy for the sake of clarity: many of us have painted with watercolors in primary school or changed a tire on a car; most can generally produce an adequate outcome at the most basic level. However, very few have the watercolor skills of historically notable watercolor artists like Audubon, O'Keeffe or Dürer. These people were masters — subject matter experts — of their watercolor painting workflow art.

Keeping with the legitimate concept of artists, few have the skills of the steel industry's trade artists: millwrights, pipefitters and other trades rebuilding specific gearboxes, rewinding motors, tuning furnace models, etc. The concept of artistry can be translated within company sites, departments, process lines/areas, and even extends to various management styles around spare parts, preventive maintenance, managing people, etc. Some people are more capable than most, making them a sort of artist.

The value of art is relative. It seems society values an artist's work more when the artist quits or dies. Access and scarcity drive perceptions of value. Likewise, in industry it seems we learn to value the workflow art of our most knowledgeable and talented subject matter experts when they aren't available; at home, on holiday/vacation, retired or simply gone. Those SMEs carry their art with them. The value of the workflow art held by the most experienced SMEs within various sets of tribal knowledge is immeasurable, incalculable and invaluable.

How do we retain that workflow art while we can? Trainer-trainee, master-apprentice and mentoring programs have long been the best method. Unfortunately, with ever-leaner, more "productive" crew sizes due to automation, and cost reduction targets, we typically don't have adequate one-to-one training opportunities necessary to convey many of the most nuanced workflows. Even with the luxury of trainer-trainee opportunities, we rely on flawed human memory to record the details of task nuance. Furthermore, many critical tasks are executed on infrequent cycles: quarterly, semi-annually, annually or longer. Human memory is fickle and fallible. Creative, safe, efficient, and valuable "tips and tricks" or "nuggets of gold" are lost. If someone does remember all those golden nuggets, there is a chance that person is on vacation, retired or otherwise unavailable the next time they are needed.

Using small video cameras (e.g., GoPro®, etc.) to record workflows is another more recent strategy some companies have employed to mitigate the vulnerabilities of lost workflow art. However, while a stream of raw video is better than nothing, its long-term utility is questionable without talented and time-consuming editing. Worse, video is useless if the camera view/focus misses the details, isn't viewed because the file can't be found, is inconvenient to play where it's needed, navigating/rewinding to the spot on the file, or an equipment/process change requires different information, etc. In the end, capturing and conveying the workflow art of an SME is a major challenge.

Some premium AR tools are specifically designed to capture workflow art, the associated tribal knowledge. The AR system permanently safeguards the tribal knowledge and enables easy access when needed. The capturing/recording process is called "authoring." The accessing process is called "using." One particularly powerful AR software system enables the SME to author their workflow art procedure directly, and autonomously, into the AR system — even if the SME has little or no experience with computers. The software allows discrete steps to be created within the procedure. Furthermore, these discrete steps can be filled with "notes" highlighting any level of nuanced detail about a particular step: short video clips, photos, PDF pages, audio, diagrams, "if-then" troubleshooting tree paths, etc.

At the fundamental level, the most complex tasks are a collection of simple action steps: push, pull, turn, pinch, grab, move, etc. Increasingly detailed, discrete steps while training a person or authoring the info into an AR system breaks down and distills any workflow art procedure into increasingly simple steps. This process exposes the golden nuggets of workflow art. These golden nuggets at the most basic level answer the question "How much of what?" For example: Push this far, pull to here, pinch this hard, etc.

Back to imagining yourself standing at a canvas with any of those historically significant artists: Audubon, O'Keeffe or Dürer. You're standing next to them with paints and brushes ready, the master explaining, pointing and demonstrating, in detail, each step of painting their style. Or the industrial equivalent: anyone standing with an expert millwright, electrician or other tradesperson. Given enough of those golden nuggets from the expert, anyone with proper tools and physical control of their body should produce an adequate copy of the expert's work.

If an average person were told, "rebuild motor Model #ABC123, Serial #789XYZ," most people couldn't simply proceed. However, if appropriate details and nuanced techniques were explained by a subject matter expert, step by step, then nearly anyone could proceed. Continuing with the example: Let's say there are 57 significant steps to rebuild motor Serial #789XYZ. Step 39 is "install armature bearings." If the average person were provided a number of nuanced, not-obvious-to-less-experienced-people level of details, with proper tools and expert nuanced guidance with enough detail, they can replicate the original workflow art, or an adequate level to succeed.

With all the discussion about empowering less-experienced workers, it is easy to ignore the benefit of AR to the SMEs. Once their bits of workflow art are authored into the AR system, those portions of tribal knowledge are "digitalized" and permanently stored for posterity. Using that previous example again of the 57-step motor rebuild, once the workflow as was authored into the AR system, the SME wouldn't be bothered again unless the AR workflow required some extra information. Say steps 14 and 23 were a little unclear. It is easy to edit authoring of those details within the AR workflow. If less-experienced workers require that workflow, they can utilize the AR system's access-anytime-anywhere capabilities to use the workflow. The SME isn't asked again and again to make time to train yet another person. The SME can stay productive with other tasks, get a good night's sleep without the cliché 4:30 a.m. emergency phone call, go on holiday/vacation without being bothered, and even retire without the organization losing that priceless tribal knowledge.

Speaking of the 4:30 a.m. support call, AR systems support remote assistance capabilities, allowing the SME to see the view of the worker needing support from any PC screen in the world. The SME can use the AR system's internet portal tools to annotate on the worker's view of the machine, visually directing them to the component needing attention. More functionality and support are also possible depending on the AR equipment. All of this saves time, expense and morale.

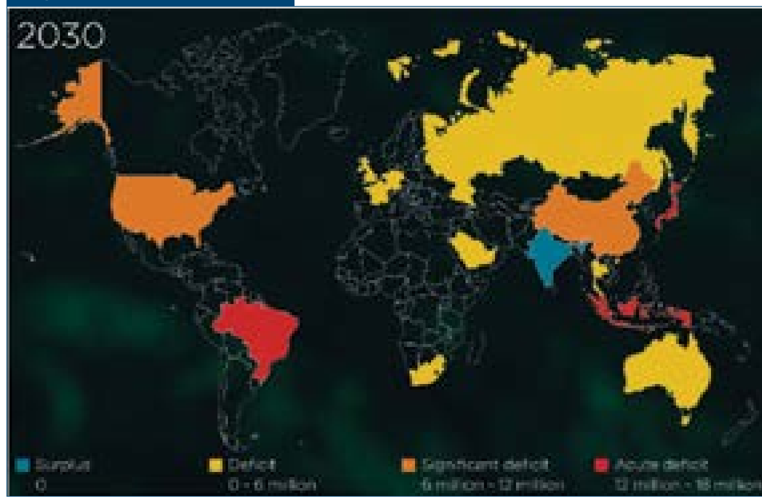
2 of 3 — Skilled Labor: Retaining and Developing: At the end of this decade, it's predicted there will be a global skilled labor shortage of more than 80 million workers, causing an unrealized production potential of more than US$8 trillion. For perspective, this means a skilled labor shortage equivalent to today's population of Germany and removing the current economic value of both Japan and Germany (the third and fourth-largest economies!) from the world's economy. A shortage of skilled labor is the cause of this "hole" in the global economy (Fig. 3).

The predictions come from an excellent, late-2018 Korn Ferry study after they surveyed companies from 14 diverse countries. Finding skilled labor is already difficult in many industrialized countries. This difficulty will only increase in nearly all countries as they will struggle to find workers with sufficient skills. The situation will generally become twice as bad every five years. Brazil, Japan and Malaysia are expected to suffer most. Significant skilled labor shortages in the U.S. and China will limit output of these two largest economies. India is the unique exception, expecting to have a net surplus of skilled workers (Fig. 4).

Figure 3

Projections of global skilled labor shortages and associated unrealized economic losses due to the skilled labor shortage.

Figure 4



Graphic projections of skilled labor shortage severity by surveyed countries.

The key word is "skilled" within the worker shortage. The difference between skilled and unskilled is an arbitrary level of knowledge and competence. In simple terms, if unskilled workers have access and ability to use knowledge, then they become skilled, perhaps "skilled enough." Of course, different people have different levels of innate abilities – a.k.a., "knack" (in English). Companies generally prefer the most capable and healthy individuals, mentally and physically. But in a situation of scarcity with companies seeking greater targets for themselves and investors, a viable solution is to train available workers. "Upskilling" is a contemporary buzzword to encapsulate this concept of training workers (new, existing, young or old) to complete an enhanced range of tasks the company requires of them.

Companies require skilled workers. It is urgent to optimize training. Even more, the most successful companies will focus on the business case of training: What is the per-unit cost of training? What is the opportunity cost of not training? What is the cost of implementing new technologies compared with the opportunity cost of doing nothing? What is the cost to implement parallel pilot programs evaluating different training methods compared to the opportunity cost of taking time investigating any/all options before proceeding, risking the situation of "analysis paralysis"? In the end, every viable company must decide a legitimate strategy for training and with what method to train.

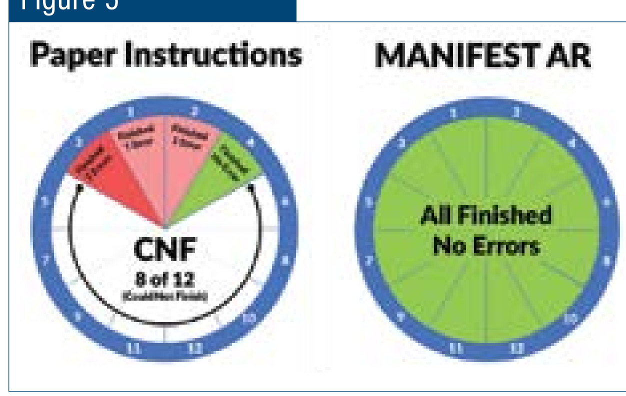
Reconsider the hypothetical scenario from the previous section with the master watercolor painters. The artist provided information to an unskilled person. The master dissected each action and motion with what, why, when and how within the context of the task, paints, tools, and techniques. In that context, it is probable that an average, unskilled person could produce a very good watercolor painting. Unskilled people with adequate information — the expert's golden nuggets — can produce adequate results.

AR has proven its effectiveness to dramatically accelerate the effectiveness of less-skilled workers within the U.S. Air Force (USAF) and other branches of military in the U.S. and overseas. The USAF conducted a study in 2018 comparing their traditional written paper manual instructions against an AR software system called MANIFEST running on a head-mounted-display (HMD) AR device called a Microsoft HoloLens (i.e., AR goggles).

Overview:

- Four inexperienced aircraft mechanics were each assigned six jobs. A total of 24 jobs were attempted.
  - Workflow information for each job was provided with either the standard paper instructions or the AR system to execute each job.
- Each of the four workers attempted each of the six jobs only once — with paper instructions or AR.
  - 12 jobs were attempted with standard paper instructions.
  - 12 jobs were attempted with MANIFEST AR.

Figure 5



Graphical results of U.S. Air Force study conducted to compare job results of low-experience airmen attempting 12 procedures with traditional paper instructions or an AR system named MANIFEST.

Results:

- Using the traditional paper instructions, the group of inexperienced airmen were able to complete one job of the 12 successfully without errors (8% success).
  - It is a matter of opinion if "completing" jobs on aircraft with errors is acceptable.
- Using the AR system, 100% (12 of 12) of the procedures were finished with no errors.
- AR saved 10% of time when comparing the average of both AR jobs completed without error to the single job complete without error using paper instructions.
- AR saved 17% of time comparing the time used for all four "completed" jobs using paper instructions regardless of errors.

There are various reasons for the significant enhancement in USAF technician performance when using AR. The strongest theory is being provided multiple bits of nuanced information within the context of the job by the AR system — the golden nuggets; the layer of digital information pointing to specific parts of the aircraft with multimedia material "notes" (e.g., videos, photos, PDFs, etc.) displayed where the technician needed to see the information (e.g., directly next to the parts they are working with).

With AR, there is minimal translating or interpretation between looking at the multimedia info compared to reading words and drawings on paper pages, pausing to convert into a mental picture and then trying to proceed with that memory on the real equipment. With AR, the worker can more easily tie cognitive patterns between the AR notes and the actual equipment.

Capable AR systems are the closest replication possible to working with a subject matter expert. Plus, the bonus of having the subject matter expert's information authored into the AR system means the information is always available. The AR system never tires of repeating information, never needs a vacation and can be called up at multiple places for multiple users, etc. Capable AR systems retain tribal knowledge, enable unskilled workers to perform complex jobs which will likely have fewer errors, and AR systems generally enhance the worker's experience and performance — helping to enhance worker retention.

3 of 3 — Worker Knowledge: Transferring Between Generations: Intergenerational friction has seemingly always been with society. That friction, along with the rest of the complex human condition, passes into the company gates each workday with most workers. Good communication and team morale are as important as ever with work crews consisting of fewer people. This can be a challenge with the stress that can accompany lean crews, especially with increased range of age between the oldest and youngest members. Surveys have highlighted the differing communication preferences between the generations.

Sociologists have classified people into general groups by the year in which they were born:

1928–1945	Silent Generation
1946–1964	Baby Boomers
1965–1979	Generation X
1980–1997	Millennials
1998–2012	Generation Z
After 2012	Generation Alpha

While people within these seemingly discrete groups have tremendous diversity, there are general biases from one generation to the other.

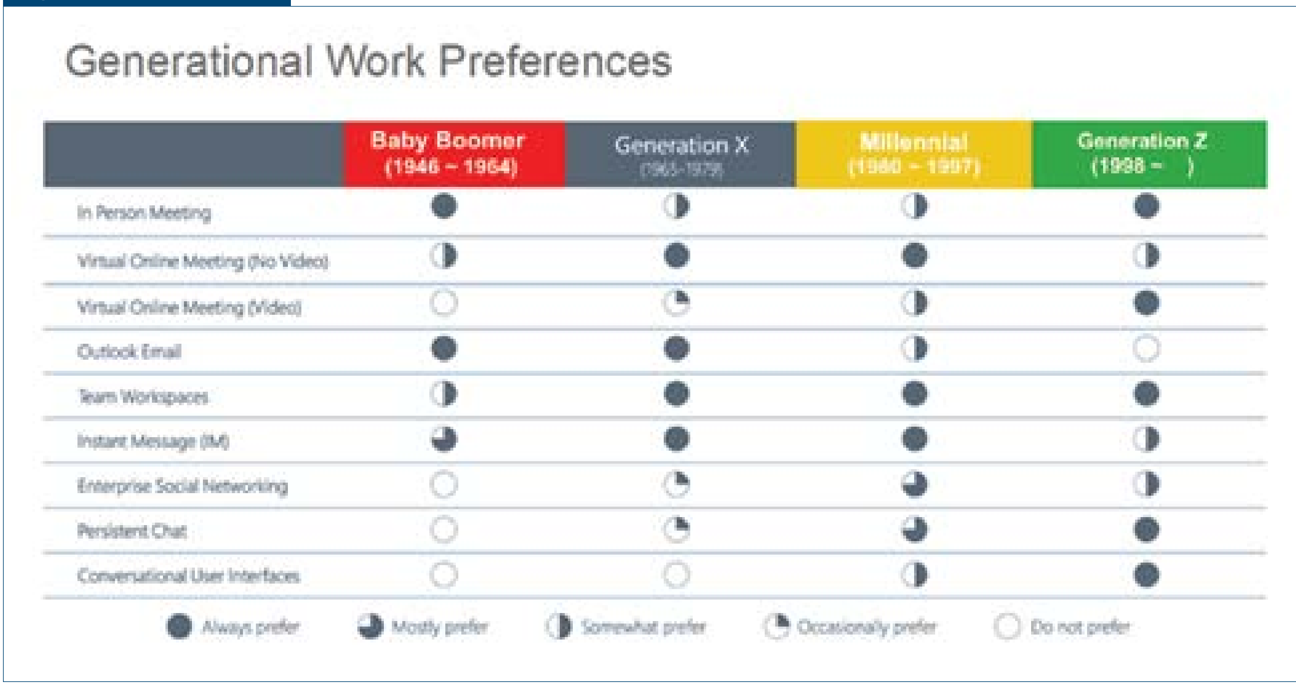
A small group of companies including Microsoft conducted a 2016 survey of individuals from four generational groups: Baby Boomers though Generation Z. These groups comprise most of the general workforce. The survey's findings supported the intuitive stereotypes most people have about these groups relative to business communications. For example, older generations prefer email while younger generations don't. Younger generations prefer various social media messaging and chats, while older generations are less enthusiastic about these newer methods of communication.

Current AR tools are well suited to help bridge generational gaps. The newest workers, typically younger, are "digital natives": they spent their formative years interacting with personal digital devices. Younger workers enjoy interacting with information through digital devices. Competent AR systems are multimedia environments accommodating most styles of learning, but are almost ideal for younger worker interaction.

Generally, younger workers will be consuming the AR system's procedural workflows as users, while more experienced, typically older, workers will be providing the information for authoring the procedural workflows. As mentioned, older people generally have less enthusiasm for interacting with digital devices than younger people. Therefore, to be an effective tool for authoring/recording workflows, the AR system's user interface (UI) must be simple, intuitive, and offer multiple methods of authoring and editing content. Content will not be authored if the UI is difficult and inflexible.

The AR system MANIFEST uniquely enables frontline workers to autonomously author their workflows at the actual jobsite, requiring no computer experience. Multiple devices (e.g., tablets, head-mounted-displays) can be used for authoring, but head-mounted-displays are best because of their more advanced spatial sensors and to allow the author to work hands-free: not holding a tablet AR device. Many AR systems

Figure 6



Graphical results of a 2016 multi-generational study comparing generational preferences of business communication methods.

allow various capabilities of authoring from an internet browser portal. The browser portal is typically the means to add documents, 3D models, most text, and any legacy photos, videos or other media.

If there is tremendous resistance from experienced subject matter experts to author content themselves, then a proven authoring technique is to have a junior technician follow and observe the SME executing the job. Along the workflow process the junior person is video recording the SME's process while the subject matter expert is showing the nuance of their technique. The junior observer is trained to anticipate clarifying questions and ask the SME when necessary. The SME can record video and audio, take photos, and place digital markers in 3D space and other details firsthand. Alternatively, all or some of these tasks can be done by the junior observer afterwards, editing the workflow procedure within the AR system. There are many more possibilities, but these are a few of the viable options to begin adopting AR systems and permanently safeguard workflows by digitalizing them: along with the bonus of endless updates and optimizations as jobs, people, and requirements evolve.

AR is not a trend. AR is the future of interacting with digital devices at work, at home and in between. AR is the way future workers will interact with equipment and obtain information because of AR's utility and the new workers' comfort with technology.

Using Augmented Reality for Safety — Fortunately, safety is a top priority of most companies within the metallurgical market. This is communicated to their employees with training and rules. Oftentimes training is presented outside the context of specific work areas or jobs, and uses standardized, rigid text-on-page templates and other situational details that may limit cognitive connection between the safety training information and the actual environmental situation. Comprehension can be questionable, especially for individuals who struggle with reading cognition.

As explained, AR's core strength is providing information directly within the context of a physical environment. This is especially useful for safety training. There is arguably no training more important. The trainee has access to any visual and auditory information deemed potential beneficial by the author(s): video, photos, speech, text, spatial markers, 3D model holograms (static or animated), troubleshooting "if-then" paths, internet hyperlinks, bookmarks to the latest PDF docs, live feeds from IoT meters, etc. A premium AR system is ideal to serve a workforce of various types of learners with different cognitive connections.

Lockout/tagout (LOTO) procedures are a central pillar of safe practices within industry. LOTOs can be very simple, e.g., throwing a single electrical switch off before locking and tagging that switch in the off position. However, many times the complex equipment used in heavy industry uses multiple energies from multiple sources and the LOTO process can be complex, with critical sequences. Making a mistake can easily cause injury or worse. (A very brief overview for those unfamiliar with LOTO practices: LOTO is the process of isolating equipment from potentially dangerous energies using switches, valves, and other devices before applying locks and warning tags to those devices that prevent energy flowing to the equipment being worked with. A few of the potential dangerous energies are electrical, pressure, gravity, etc. All hazards to workers must be mitigated before servicing equipment. Very generally, this is the LOTO process.)

Furthermore, the sequence of restoring energies and services to the equipment after the work is complete is also important for the safety of workers and equipment. For example, it is very easy to damage furnace components if a cooling water supply restoration procedure is mishandled as the furnace becomes hot.

LOTO procedures are an especially applicable to AR. The importance of detail and sequence, relative infrequency of some, and a feeling of limited time are some of the most obvious reasons. Fig. 7 shows the AR user's point of view wearing a Microsoft HoloLens2 head-mounted display in the midst of an AR LOTO procedure. The photos provide a sense of the utility to the user. The left photo demonstrates verifying a three-phase electrical service with ground is properly configured. The instructional video is placed directly next to the device. In the center photo, the AR video provides detailed instructions of which arm to use when throwing switch and how to avoid arc flash risk. The green arrow serves as a visual cue for which switch lever to throw. In the right photo, the user sees details of how to apply the LOTO lock to a particular pneumatic valve after the video showed the proper technique of closing the valve and what to expect from the equipment at closure.

Another aspect of plant safety where AR can assist is showing when and where dangers exist. Sometimes dangers are obvious, but inexperience can be deadly. We don't know what we don't know; although ignorance isn't generally acceptable, it does exist. AR can provide visual information to highlight anything deemed dangerous for training. Fig. 8 shows two static photos pulled from video feed of the AR HMD. Shapes can be placed in space around areas for safety training. In the left photo, the red rectangle highlights where heavy or tall objects should not be placed because of the danger they could fall on someone below. In the right photo, the red and yellow

Figure 7

Photos captured from first-person view of a HoloLens 2 head-mounted display while the operator is executing lockout/tagout tasks. Details explained in the text.

Figure 8

Photos captured from first-person view of a HoloLens 2 head-mounted display showing simple examples of how AR can be used to train workers of danger within manufacturing areas. Details explained in the text.

Figure 9

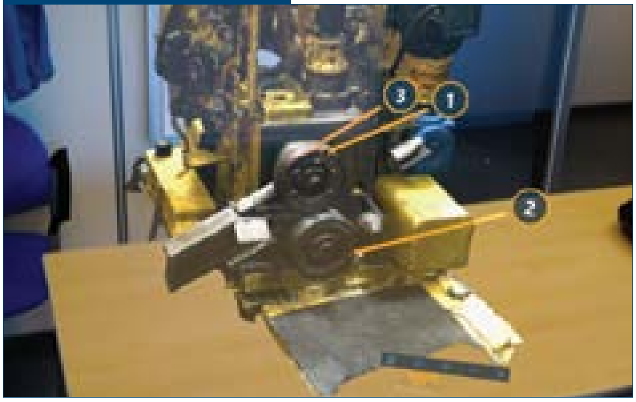


Photo captured from first-person view of a HoloLens 2 HMD showing 3D model of continuous galvanizing line edge-trimmer projected in a conference room allowing off-line training in a safe environment. Details explained in the text.

rectangles placed in 3D space show especially dangerous areas to avoid when machines are operating.

This same concept could be applied to any manufacturing area. An AR safety procedure could exist on an AR-enabled device (e.g., a tablet, head-mounted display) ready for anyone's training, annual refresher course, etc. The depth of the training is limited only by the imagination of the AR author. Videos, photos, PDFs, audio, web links, if-then routes, etc., are all possible for such training or overview. Evidence of the trainee's progress through training can be recorded within the AR system to verify understanding. In fact, saving evidence of understanding can be authored as mandatory: the user must create a record of understanding. There are many options to create evidence.

Fig. 9 is a final example of AR enhancing safety. In this case, a 3D model of a sidetrimmer from a flat-rolled finishing line is projected within a conference room. AR enables users to become familiar with aspects of equipment using a 3D model safely projected in within the safe area of a conference room, office space, hotel room, etc. (These 3D models of existing equipment are easily obtained with a process called photogrammetry. Another option is using LiDAR scanning functions common on some newer mobile phone and tablets.)

Some equipment like this sidetrimmer, inside furnaces, mill basements and other confined spaces have limited opportunities for workers to become familiar with servicing because the components are simply inaccessible while the line is running. 3D models enable workers to become familiar with the physical details of the real equipment and even practice workflows before a scheduled shutdown. The 3D models can be manipulated to show internal parts, exploded views and any other conceivable animation to empower worker competency. The worker can develop a stepwise familiarity and muscle memory around the 3D model. This has the potential of greater efficiency and safety when working on the actual equipment during the scheduled maintenance period.

Conclusions

Some facts:

- AR is ready to help frontline workers be safer, more proficient, more efficient and perhaps enjoy other benefits such as job satisfaction by having instant access to useful information and completing tasks.
- AR is a powerful means to safeguard an organization's invaluable tribal knowledge that is threatened by shifts in demographics beyond the control of any person, company or country.
- AR is not a trend; it is the future of interacting with digital devices. Every organization will eventually need to choose when they adopt AR just as they had to choose when to adopt desktop PCs during the 1980s and 1990s. There are upfront costs to adopt new technologies like AR and tremendous opportunity costs to delay adopting. AR can and will help workers be safer and more proficient.

There are other aspects and benefits of AR not discussed in detail at this time, such as teammates being able to interact within the AR app to working together on the same procedure from different areas, increased efficiencies by being able to provide evidence of faulty equipment and evidence of jobs finished. There are more aspects to AR beyond this paper. In the end, AR will be revolutionizing the frontline worker with IT tools. It's important for companies to determine their AR strategy for the company and its workers.

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