ELECTRIC POWER RESEARCH INSTITUTE

Program on Technology Innovation: Augmented Reality—Literature Review of Human Factors Issues in the Electric Power Industry

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ABSTRACT

Augmented reality (AR) is a technology that combines real and virtual information presented in an interactive way in real time. AR employs presenting digital information to a user in the real world through tablets, smart glasses, headsets, and helmets. AR has applications in many fields: entertainment, education, navigation, military, industrial, and electric utilities. AR is growing rapidly and will likely be used by a significant percentage of the work force in the next 10 to 20 years.

There is a paucity of human factors and occupational safety research for AR devices in the electric power industry. Important human factors and safety issues are physical strain (force of the neck and back muscles), cognitive loading, eye strain, and situational awareness. Results of preliminary studies that have investigated AR with respect to these issues are described in the report. In addition, researchers do not know the long-term effects of employees using AR devices daily for sustained periods of time. Guidelines for the appropriate amount of time for safe and effective AR usage are lacking.

AR wearable devices are evolving rapidly, and their form factors will become smaller, less cumbersome, and more pervasive in the future. Examples of future forms of AR are contact lens (which may replace head-mounted gear), smart clothing embedded with AR devices, and AR devices embedded in the Internet of Things. A deep understanding of how these future forms of AR will affect human factors and safety issues is imperative before AR is integrated into electric utility work.

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PRIMARY AUDIENCE: Utility safety and occupational health professionals

SECONDARY AUDIENCE: Utility ergonomics and safety teams, ergonomics practitioners, asset managers and engineers implementing work practice technologies

KEY RESEARCH QUESTION

Augmented reality (AR) is an emerging technology that is being demonstrated, and will likely be used by electric utility workers in the near- and long-term future. A review of the human factors issues of AR device literature that apply to electric utility field workers is needed in order to apply AR technology considering worker health and safely.

RESEARCH OBJECTIVES

The objective is to conduct a literature review of AR technology that may be applied to electric utility workers and identify the human factors issues that should be considered for future research and before implementation of existing and future technologies.

KEY FINDINGS

- AR is the combination of real and virtual information presented in an interactive way in real time. AR employs presenting digital information to a user in the real world through tablets, smart glasses, headsets, and helmets.
- AR has applications in many fields – entertainment, education, navigation, military, industrial, and electric utilities. AR is growing rapidly and will likely be used by a significant percentage of the work force in the next 10 to 20 years.
- Early research in the field of AR devices focused on the technical functionality of the device. Some present research focuses on the human factors issues of AR devices, although research is limited in industrial applications (which includes utility field work). Important human factors and safety issues are physical strain, cognitive loading, eye strain, and situational awareness.
- Present wearable AR systems use either a helmet or head-mounted device, and the effect of these devices on neck and back muscle forces has not been quantified.
- There has not been a suitable framework to assess cognitive load in past research, and as such, cognitive loading results have been piecemeal. There is a need to establish a cognitive load framework that is generalizable to many applications of AR.
- AR may cause eyestrain, which may be manifested by headaches or blurred vision or even delayed hand-eye motor coordination. AR can superimpose graphics on a user’s view of the real world, and if these graphics are not clear or easy to read, then eyestrain may develop.
- Situational awareness is the ability of the user to conduct activities of daily living (ADL), such as walking and climbing stairs, while using AR systems. Users must be able to perform ADL tasks along with basic electric utility tasks (e.g. correctly identifying conductors) safely and efficiently while using AR. Assessment of situational awareness from AR devices in the utility sector is lacking.

- AR is a fairly new technology and researchers do not know the long-term effects if employees were to use these devices daily for sustained periods of time. Guidelines for the appropriate amount of time for safe AR usage is lacking.
- Human factors knowledge gaps for AR devices in electric utility work are identified.

WHY THIS MATTERS

AR applications are being demonstrated by some electric utilities on a small scale. Before AR can be deployed on a large scale across electric utilities of different sizes, the human factors issues should be identified to ensure appropriate and safe deployment of AR.

HOW TO APPLY RESULTS

Utility personnel can use information from this report to inform their decisions in developing and implementing work practice procedures, and in considering wearable AR technology procurement. This report also provides insights for developing research plans to address knowledge gaps.

LEARNING AND ENGAGEMENT OPPORTUNITIES

Utility personnel can use findings from this report to engage developers and manufacturers of AR technology for appropriate and safe use by electric utility workers. Two published EPRI reports may be helpful to utility personnel.

Program on Technology Innovation: Enterprise Augmented Reality Vision, Interoperability Requirements, and Standards Landscape. EPRI, 2017, 3002010514.

Program on Technology Innovation: State of the Art of Wearable Enterprise Augmented Reality Displays. EPRI, 2016, 3002009258.

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INTRODUCTION

1.1 Augmented Reality

Augmented reality (AR) is the combination of real and virtual information presented in an interactive way in real time. AR operates and is used in a 3-D environment, and it employs a superimposed overlay of digital information on the real world. It allows the user to have awareness of their environment while enhancing their perception or knowledge of a task through additional displays or audible and tactile cues. In some cases, mobile smart devices such as tablets or smartphones use their cameras to create an interactive interface that combines the view of the consumer with the physical environment and overlays texts, graphics, and other media files that have been "geotagged" to specific coordinates on the earth's surface. In addition, many AR browsers on different devices incorporate image tracking software to create digital overlays on top of print media, building facades, and other environmental structures.

1.2 Virtual Reality

Virtual reality (VR) is defined as "a completely artificial digital environment that uses computer hardware and software to create the appearance of a real environment to the user" [1]. The display technology can be worn or in a fixed placement. The device gives the user an immersive and sometimes stimulating experience within a 3-D computer model or simulation [2]. The two main methods of achieving the immersive environment are by wearing a head-mounted display (HMD) or by being in a projection-based system such as computer-assisted virtual environments (CAVEs) and domes [2]. VR does not allow the user to have a presence in the real physical environment as AR does. Therefore, individuals cannot safely carry out activities of daily life (ADL), such as walking around or climbing stairs, while wearing or being immersed in VR devices.

1.3 Mixed Reality

Mixed reality is the merging of augmented and virtual reality that takes place in both real and virtual worlds. In mixed reality, objects in the actual physical surroundings play a direct functional role within the virtual environment simulation [2, 3]. Mixed reality has varying degrees of real and virtual elements. Mixed reality is primarily used in the entertainment and gaming industry, for example, in a game where individuals go into a physical space that is featureless and then they put on a headset. The environment then becomes detailed with graphics and sensory-filling aspects. Individuals can go through the physical location as they would in a VR game but will have the ability to touch walls from the real physical space and move to different floors or through tunnels. This immersive gaming experience can also be enhanced with other sensory effects such as misting, heat, smells, wind machines, and surround sound [2]. Mixed reality is a growing market for entertainment, but unlike AR, mixed reality has yet to infiltrate multiple work environments outside of training applications.

1.4 Augmented Reality: Present and Future

Augmented reality is often confused with virtual reality and tends to be assumed by the public as an entertainment-only tool. However, since its inception, AR has been growing and is used in several fields to enhance performance and efficiency and to ensure a safe working environment. AR has been proven to be effective in some tasks and continues to be researched in areas such as entertainment, education, military, navigation, and industrial.

The version of AR differs in each context through the various forms of tablets or smartphones as well as headgear, displays, and projection. With each of these diverse uses and contexts, AR has great potential [4]; in the past two decades, research has been conducted on commercially available and emerging devices. Many technical issues of AR technology addressed in early research have now been improved. However, there are still evolving issues with the technology and the devices with regard to human factors [4].

AR can be used on several platforms [5]. HMDs and heads-up displays (HUDs) are common tools that developers choose to create their software and applications when users need to have a hands-free experience [2]. Whether the user is driving, carrying a package, or using weaponry, the hands-free information and real-time accurate displays are necessary for efficient and safe operation and completion of tasks [2, 3].

HMDs for AR must be see-through-displays (STDs) so that the user is aware of their surroundings and not have their vision impaired by the information presented on the headset [6]. When wanting to display information to a larger group rather than an individual, AR projection tracking and mapping is a useful tool. It is used in various fields to project images onto real-world objects, such as in a hologram [3]. This could be done to show what a room would look like after a renovation or in meetings to present a new design for a product [3].

Although augmented reality is not a common term in all U.S. households, it is expected to become one soon. Digi-Capital, a firm of merger and acquisitions advisors in California, predicts that $108 billion a year will be spent on AR and VR combined through 2021, and AR will account for three quarters of that annual amount [7]. The growing market of AR is corroborated by another source that estimates that AR will be a $100+ billion industry in 2020 [8].

The users of AR are expected to be primarily businesses and corporations, and not consumers. Test studies of AR in the logistics industry have shown that AR increases productivity and quality. DHL workers' use of AR has resulted in productivity gains of 25% along with fewer errors and more engaged workers [9]. Intel has achieved a 29% reduction in picking time in their warehouses with AR [9].

The predicted economic boom for the AR industry and demand for its products requires multiple fields to work together to produce successful AR devices [10]. The projected deployment of AR will affect jobs in corporations, military, navigation, and industry—with the goal of enhancing worker experiences, efficiency, safety, and ergonomics.

This report describes the specific types of AR in multiple fields, including a discussion of AR for electric utilities. Studies of the human factors issues of AR will be summarized, and human factors research gaps will be noted.

2

TYPES AND USES OF AUGMENTED REALITY

Many types of augmented reality are available within the entertainment, education, military, navigation, industrial manufacturing, and electric utilities sectors. Specific types and uses of AR are noted in each domain.

2.1 Entertainment

The public became acquainted with mobile augmented reality (MAR) during summer 2016 when Pokémon Go was released [11]. The game allowed the maps on the mobile devices and cameras to be accessed. When individuals would point their camera at the road, the road would be presented on their screen with an additional figure of a Pokémon. This interactive game took advantage of technology within mobile devices as well as consumers' strong understanding of how to use these devices and their dependency on it [11]. Pokémon Go was a successful incorporation of AR in an affordable setting to the public. This game displayed the accuracy and sensitive target ability of location geotagging, giving the world a taste of what is to come with AR.

Augmented reality has been embedded in science fiction novels, films, and television. In the movie *Star Wars*, characters wore helmets with data uploaded on the side view and target sensors to shoot at the Death Star or to project Princess Leia from a small robot into the air in a 3-D form. Such AR technology is now accessible to the public. Tools that were once thought to be fictional and only in movies are now being made for the mass consumer in addition to being more affordable.

Entertainment sectors such as films and media sources are incorporating AR as part of their marketing plan. By creating interactive trailers on YouTube or movie ads in magazines, producers are engaging fans in new ways. For the latest *Star Wars* movie, fans were able to point their Apple I-Pad camera at a magazine page to find a Death Star floating on the magazine in front of them.

Magazines are allowing tech savvy readers to participate and enjoy additional visuals and interactions through AR. By using devices such as tablets and smartphones, individuals may interact and enjoy apps—often at no cost. Static magazine covers on store shelves now can become videos with the use of apps on smartphones. This clever marketing trick enhances the sense of interactivity for the reader; it also helps keep this print medium alive for the digital generation, particularly millennials.

Other types of entertainment incorporating AR include Facebook, which is hoping to expand its enterprise into an AR or VR platform [12]. Facebook founder Mark Zuckerberg recently stated that the company is building AR hardware, with the hope of having Facebook on the cutting edge of the next technology boom to the public [12, 13]. Zuckerberg also explained that work is needed to bring AR out of the primitive tool phase and to reach new audiences [13]. Other social media apps such as Snapchat use AR as a part of their main use. Users of Snapchat can wear filters on their faces through mapping technology. The app places wigs, eyes, glasses, or animal ears onto individual users' faces [14]. Moreover, there are new world lenses that overlay the world image on the camera [14]. These world lenses can be created by businesses and cities to promote their name, brand, or location.

Apps are continually being released for several purposes in the entertainment field and provide opportunities for users to enhance skills. The ability to use AR apps depends on the software in the devices. For basic uses, AR is overlaid using the device's rear-facing camera, and the image is overlaid on the screen on the displays. This ability has enabled the gaming industry to branch out into new possibilities. Even simple games such as an AR-based table card game combines modern digital technology with tradition to cater toward an older audience [15]. AR apps can be used for a wide age range of consumers with varying abilities and can entertain individuals and enhance skills through AR design [16]. With educational game apps as an entertaining and fun source, users may also build skills to improve academic performance.

Despite the fun and exciting possibilities of being entertained using AR, there are privacy and other concerns with uses of AR capabilities and devices. Privacy is a primary concern with individuals having HMDs [17]. The possibility of recording others without their knowledge while wearing a device such as Google Glass has led communities and businesses to ban the wearing of the device [17]. Moreover, as social media merges with AR and devices become more widespread, some fear that society may become more driven by social status (as a result of "likes") and that public perception and personas will become extremely important [18]. These concerns are grounded in some truth: smartphones and social media have drastically changed the social climate and created privacy issues with the accessibility of cameras, live streaming, and instant sharing [18].

Table 2-1 lists AR uses in entertainment.

Table 2-1
Augmented reality uses in entertainment

Device	Reference	Pros*	Cons*
AR Tag	(Chi, Kang, Wang, 2013) [19]	● Virtual metadata ● Worldwide	● Lowers interpersonal communication
EyePet by Sony	(Chi, Kang, Wang, 2013) [19]	● Game ● Interactive pet ● PlayStation or PSP	● Older game ● Lower quality graphics
Google Glass	(Levy, 2017) [20]	● Lightweight ● Sleek	● Privacy concerns ● Personal interactions affected ● Rudimentary graphics ● Static display
Layar	(Chi, Kang, Wang, 2013) [19]	● Compatible by most smart devices ● Can be used by various companies to enhance products ● Creates engaging content ● User friendly	● U.S.-centric content ● Some layers cost more to use
Mira Prism	(Heater, 2017) [21]	● $99; affordable ● Incorporates smartphones	● Not visually aesthetic ● Bulky
Microsoft HoloLens	(Tilley, 2016) [8]; Aukstakalnis, S., 2017) [2]	● Quality built ● Resolution impressive ● Spatial sound is excellent ● Hands-free, easy interaction ● Clear vision ● More comfortable than other products	● Short field of view ● Rare software availability ● Short battery life ● Not easy to fit properly ● Glitchy ● Expensive
Smart Devices	(Aukstakalnis, S., 2017) [2]	● Convenient ● Accessible ● Compatible with many AR apps	● Less immersive ● Varied clarity of lens and screen ● Phone abilities vary

*Pros and cons were reported in the corresponding references.

2.2 Education

Often it is the education field that attempts to find new ways of incorporating technology to enhance learning [1, 22]. To keep students up-to-date with the changing technology climate—and to keep their attention—schools of all age groups are incorporating AR as a possible tool in the classroom [22]. In pre-K through higher education learning, and even in the world of business training, AR is evolving to become a staple of education in all subjects [23]. In particular, AR is being used in the science, technology, engineering, and math (STEM) field because of its ability to allow for more laboratory time, experiments, or use of virtual manipulation [24]. AR also helps promote enhanced learning and achievement [25] and encourages students to develop critical thinking, problem solving, and communication through interdependent collaborative exercises [26].

Primary schools are adopting AR as an E-learning tool; however, there are challenges—procuring the software and devices through funding, training the teachers, and having teacher acceptance of technology in the classroom [27]. As the young, digital native population continues through primary and secondary school, teachers are attempting to ride the momentum of the students' technology skills by creating technologically rich environments. One way teachers are achieving these environments is by incorporating AR into the curriculum. Some teachers find this helpful because using technology can influence students to learn actively, resulting in an effective learning process [27].

AR allows for realistic hands-on experiences in which students feel immersed. Unfortunately, many schools are not financially able to devote the funds to access AR technology. If the school acquires AR, the teachers must be willing to train, learn, and plan lessons around the technology.

Besides the typical setting of a school, AR is used in educational environments such as training employees in various fields. Often there are rapid changes in different fields provoked by increased competition and pressure to reduce the cost and time to develop new products or services [28]. To address these rapid changes in the workplace, AR headsets with computer information can project or present information in real time, updating the user with vital information to efficiently and safely carry out their job. The AR headsets in this case are educating the user on the new changes, helping workers learn more "on the job" and deal with day-to-day problems—eliminating a need for outdated learning manuals that often take too long to find or print [28]. The AR benefits for training also facilitate a trainee's information search and may reduce error. Using AR in training has been found to facilitate comprehension and retention of information [28]. Because of its applicability and usefulness, AR may become a standard tool for training workers.

AR not only provides up-to-date information in real time, but it also allows for hands-on experience in a safe manner [1]. AR is not just for headsets and projectors but can be used with tablets and smartphones so that students or employees may have accessibility to continue work at home. Some textbooks can be used on multiple platforms through AR and are therefore able to enhance learning and retention. Medical students can bring their textbooks to life and manipulate objects visually or perform surgeries without the need to practice on a cadaver. The overlay of images in the real world allows students to feel immersed in the moment but still have spatial awareness [3].

Health rehabilitation training has also found ways to incorporate AR with elderly individuals to teach them proper form and to train individuals on the proper posture and movement after hip replacements. Using an AR treadmill, physical therapists and medical personnel may enhance their patients' experience and their expediency toward recovery [15].

Training of instructors both in educational and corporate environments is necessary to be able to use and apply these tools. Professional development sessions would need to be scheduled and include trainers to teach the educators how to use the devices to their full potential. This could be costly for the institutions and time consuming, however. The cost for buying the equipment for a large group of individuals tends to be expensive and therefore not always an option for schools. Furthermore, devices used in schools sometimes fail because of frequent use and wear, requiring replacement.

To encourage incorporation of new technologies in classrooms, the U.S. government and other organizations have created grants for D-12 and higher education [29]. As AR technology becomes more available, prices will probably decrease—making AR more accessible for the classroom setting. The next generation of students will potentially have the opportunity to learn in an immersive and enriching environment, incorporating AR into daily lessons.

Table 2-2 lists AR uses in education.

Table 2-2
Augmented reality uses in education

Device	Pros	Cons
Headset	• Individual experience • Can be used for several lessons • Assists in retention and comprehension of hand-eye motor skills	• Ergonomics of comfort and eye strain • Usability issues • Cognitive overload
Monitor display of headset view	• Shared visualization • Useful for whole group instruction • Useful for demonstration of individual work	• Frequent technical problems
Projector-image overlay	• Shared visualization • Useful for whole group instruction	• Limited in current applications
Smartphone	• Most students will have one accessible • Activities can be performed through videos and apps downloaded	• There may be issues with the apps or personal phone • Certain phone types or generations of phones are not able to process AR software

2.3 Military

The military often has been on the cutting edge of technology, preceding deployment to consumers. The inventions of radio, mobile phones, computers, and the Internet have enabled the military to improve VR and AR technology [15]. The military improvements and research have focused on the acuteness of the eye gear and the accuracy of targets for combat purposes as well as reaction time [15, 30, 31]. Research as early as 2000 described the improvements and tests to take advantage of this emerging technology [32], which is needed to ensure the safety of the soldiers as well as the civilians in the area. Future conflict and military actions will likely often occur in urbanized terrains, requiring information for building plans, directions, hazard detection, and group coordination [32]. This dynamic and changing environment requires technology that can provide real-time information along with accuracy [32]. The military is using AR, typically HMDs, in urbanized terrains.

HMDs in conjunction with powerful computer systems, such as iLeader warfighters, allow soldiers to keep their hands on their weapons while still being able to communicate, signal, and receive information [32]. The HMDs from Waveguide Optics are optically transparent, physically robust, lightweight, require low power, and can present symbolic information over a useful field of vision [30].

The military's resources and research will pave the way for wearable devices for civilians in different situations. A specific example is smart clothing, which is connected to the Internet and can send messages through physical gestures. One HMD uses the iLeader system, which has speech recognition ability. It also collaborates with other aspects of the smart technology on the uniform, such as sensors in the watchbands or gloves to register hand gestures to send information to the entire squad. In this case, soldiers can communicate with their fellow troops [29, 30]. This software improves communication and soldier safety and may prevent accidents because of misunderstandings from lack of sight or hearing (due to long distances or noise).

Military research has looked at the issues of cognitive ergonomics as a result of using AR headsets. In a 2001 study, Yeh and Wickens [33] found that if the device did not accurately hit the target using AR, the user was going to distrust it and not use the technology. But if the device accurately hit the target immediately, there was possibility of over-trust and overuse of the device. The study concluded that more research was needed to determine the long-term cognitive effects of using AR devices consistently [33].

Concerns over cognitive load strain on individuals require human factors guidelines [33], which would give researchers a platform to compare different AR devices as well as provide guidance on how to measure cognitive load. One theory that is discussed in military research articles is Human Information Processing Theory (HIPT) [31]. Various models for HIPT were developed to measure tasks of an individual to note the flow of information in different stages. These models assist researchers with predicting response time, error rate, type of errors, and other aspects of performance. HIPT is used to track the progress of individuals with their accuracy, speed, and completion of the task while wearing AR devices [31].

A decade of military research on AR has helped developers achieve greater application of AR. The integration of AR with clothing and other sensory devices will appear more often in the future and may become a staple of daily life. Furthermore, the military is helping to create regulations and tests to better improve the safety of AR devices, which will likely result in technology transfer to the consumer market.

Table 2-3 lists AR uses in the military.

Table 2-3
Augmented reality uses in the military

Device	Reference	Pros	Cons
ARC4 system	(Prigg, 2014) [34]	● Designed to fit onto a helmet and give live updates ● Can overlay maps and other information onto soldier's vision	● Can it be hacked? ● System lag between moving of head and seeing of objects
BARS (Battlefield Augmented Reality System)	(Gabbard, Hix, Swan, Livingston, Hollerer, Julier, Brown, and Baillot, 2003) [35]	● Assist military in urbanized environments ● Environmental information and coordination information can be exchanged ● Trackers on devices ● See-through display ● Real-time information	● Not revealed in report
Waveguide Optics See-Through Display with *iLeader* computer system; later renamed *Waveoptics*	(Argenta, Murphy, Hinton, Cook, Sherrill, and Snarski, 2010) [30]	● HMD ● Optically transparent ● Physically robust ● Lightweight ● Low power ● Able to present symbolic information over useful field of vision ● Increases situational awareness	● Unknown ● Limited information released

* Pros and cons were reported in the corresponding references.

2.4 Navigation and Travel

As AR technology and affordability improve, so will the penetration of AR in all aspects of life. From aerospace to railways to boats to driving a car, AR can help individuals navigate from Point A to Point B [15, 36–44].

The main AR devices for navigation use HUDs [5, 36, 42]. These devices help provide better information to navigators and assist with situational awareness [38]. AR technology to improve situational awareness can be deployed on small to large vehicles, including ships that use the cameras and parameter lines to dock or avoid other ships. Some of the HUDs show rear and side views of the vessel, creating an information-rich environment [38]. Airplanes can use AR cameras for landing safely on runways [36, 39, 42].

AR features are becoming more readily available to the public; for example, AR detection of hazardous objects and assistance in low visibility increase safety for drivers [43]. Many new models of cars are being advertised for their safety and situational awareness from having back-up cameras with AR graphic lines over them to show distance and direction to parallel park or back out of a driveway [43, 45]. These devices can help drivers of many skill levels, age, or ability [43]. The driving cameras, for example, are useful for young and elderly drivers who need extra assistance or may have poor vision. In this way, AR may promote independence of elderly with their activities of daily life.

The AR devices used in travel and navigation are often hands-free and therefore make it possible to multitask in tested environments [44]. Rather than texting and driving, texts can be displayed on windshields, and texting back could be sent through verbal commands [44]. Although some states are hesitant to have texts in HUDs on windshields, tests are being done to ensure that it does not deter from driving focus or safety. This is a fertile area for AR research in the near term.

Up-to-date maps can also be displayed on HUDs or in MAR systems. These maps are accessible through apps and are integrated with existing products in real time. The AR apps can be useful to groups as well as individuals [40, 41]. Google Maps, in particular, has created opportunities for roads and locations worldwide to be viewed from the air or street level. Biking helmets such as DCA Optic have a visor that shows the pathway for directions. It shows colored lines to direct riders which way to turn and which road to take and includes views behind the bicycle. These visual aids reduce the need for bicyclists to look down, promoting more awareness of surroundings.

Many of the AR possibilities in travel and navigation are useful for the tourism industry as well [3]. Individuals can point their smart devices at landmarks, and pop-up displays will provide pertinent information about the landmarks and surrounding features. This application can enhance self-guided walking tours, encourage tourism in new places, and promote awareness of important local landmarks [1]. Museums are beginning to add interactive technology to encourage visitors to walk through their collection [1]. Displays with limited information with a plaque on a wall can now have interactive and multifaceted information available through AR and tablets [1]. Moreover, language translation on AR devices can assist with translating printed words from one language to another in real time using the video in smartphones. The app Word Lens does not require the Internet and so can assist in limited or no-coverage areas [1].

The navigation and travel industry has found numerous uses for AR and continues to improve the technology to provide the most effective and easy-to-use software. Accuracy, latency, and interface technology will most likely continue to improve and enhance the functionality of AR products [46].

The varied uses of AR in the travel and navigation sector demonstrate that AR and its network of apps may be a useful, efficient, and safe choice for employees and civilians. As AR technology improves and more apps are created, the possibilities will continue to grow. The growth of AR in navigation seems like a natural progression—throughout history new technologies have allowed for new ways to travel and navigate throughout the world. With AR integrated into planes, trains, and automobiles, it is only a matter of time before we see it as a part of our daily life [37].

Table 2-4 lists AR uses in navigation and travel.

Table 2-4
Augmented reality uses in navigation and travel

Device	Reference	Pros*	Cons*
HMD VR Glasses model 3120-2 Sight, Firma Sensics	(Faust, Roepke, Catecati, Araujo, Ferreira, and Albertazzi, 2012) [47]	• Useful • Good for economy • More sales of products	• Possible eye strain
HoloLens, Microsoft-Headset	(Economist, 2017) [7]	• Tracks position of user's head • Self-contained computer that needs no accessories • Can work collaboratively with other users	• Mainly for business-only clients • Expensive • Clunky and not fashionable
HUD in car on windshield	(Plavšić, Bubb, Duschl, Tönnis, and Klinker, 2009) [42]	• Improves "eyes on the road" time • Displays navigation information • Displays current and desired speed as well as distance to vehicle in front	• Need to better synthesize and integrate information in a way that does not distract and obstruct view
HUD	(Bertuccelli, Khawaja, and O'Neill, 2014) [36]	• Hands-free • Safer multitasking	• Not approved as safe in all states for driving machinery
Magic Leap Glasses	(Economist, 2017) [7]	• Clear and crisp images • Affordable	• Production quality not as high as that of more expensive products
Meta Glasses	(Robertson, 2017) [48]	• Wider view than HoloLens • Can handle virtual objects by picking them up and rotating them • Comfortable	• Unattractive • Still in design phases
Smartphone usage	(Economist, 2017) [7]	• Consumers are comfortable with device • Many are reliant upon device • Cost effective to team up with phone manufacturers • Apps can be made easily available	• Not compatible with all platforms and apps • Short battery life
Tango-Google, Lenovo	(Economist, 2017) [7]	• Provide phone with sensors to "detect the shape of the world around it" • Multiple apps • Sensible and entertainment uses	• Limited to phones or devices with Tango included • Not yet for general public use • Drains device battery quickly
Vuzix AR spectacles, Google Glass, Google	(Economist, 2017) [7]	• Allows for hands-free reading of information • Increases efficiency	• The general consumer editions do not do well in the market • Limited interpersonal interactions • Privacy concerns

*Pros and cons were reported in the corresponding references.

2.5 Industrial and Manufacturing Processes

An area that is in need of AR technology is the industrial and manufacturing fields [46, 47]. Hands-free AR devices allow for those working in factories or warehouses to have more mobility and independence and to work more productively. As a result, an organization called *Augmented Reality for Enterprise Alliance*, or AREA, is investing in research to determine how to best improve AR technology for appropriate and safe use for workers while considering human factors issues [49].

AREA is the only "global member-based organization focusing on accelerating AR adoption through creating and expanding a vibrant technology ecosystem" [49]. AR technology developer companies as well as those who use AR collaborate to deliver content and programs to achieve operational efficiencies [49]. AREA releases newsletters as well as reports to better inform its members of suggestions for AR use. One report describes a design and development process, Suggested Steps for Likelihood of Success, which focuses on the chronological sequence of design and the accompanying necessary decisions [50]. These steps allow businesses to avoid common design issues that may delay projects, waste resources, and annoy consumers [50].

There is a body of research that has been done on current AR devices for industrial and manufacturing applications as well as suggestions for improvements. Each sector of the field has different needs for AR. In automobile mechanics, AR technology can hold information on every brand and model of car and project overlays of parts needed or identify problems under the hood of vehicles [1, 19, 28]. In manufacturing, AR is used to design products and present prototypes [47, 51, 52]. This assists with creating new and better products, expediting the process from idea to creation, and allows for better visuals when describing new ideas [47]. In factories, individuals can wear the new Google Enterprise Edition Glass to perform hands-free work putting together motors for tractors [20]. In work places like these, the headwear of AR glasses provides more information with graphics and speech commands that control the images on the glasses [20].

Another advantage of AR in industrial and manufacturing settings is that manuals can be accessed using computer cloud systems [1]. Manuals that are frequently updated no longer need to be printed but can be uploaded to the AR devices, saving time by obviating workers' need to stop, read, or search for information [19]. AR manuals would also be easier to understand if they were more than just text and 2-D photos. Future AR manuals may have 3-D graphics overlaid on the actual equipment with step-by-step instructions assisting workers in real time [1]. This AR application is particular suitable for employees in controlled environments such as warehouses, factories, and buildings. AR's ability to allow individuals to receive information quickly not only makes employees more efficient, but it may also increase their safety [35].

Due in part to early tests of AR in industrial and manufacturing jobs, there is more potential for smart factories. Smart factories, which are predicted to make up 21% of manufacturing in 2022, are estimated to increase manufacturing efficiency by 27% over the next five years [53]. Smart factories will employ workers who wear smart glasses, and 14 million U.S. workers are estimated to wear smart glasses in 2025 [20]. Smart factories combine technologies of the Internet of Things (IoT), robotics, data, artificial intelligence, and AR devices to create a collaborative machine and worker environment [20, 46, 53, 54]. AR allows personnel to work alongside their intelligent machine coworkers, particularly in areas such as aerospace, defense, industrial manufacturing, and automotive [20, 53].

AR is advantageous in controlled environments of factories and warehouses. Weather and other external factors do not affect the equipment, and the location stays the same daily. The controlled environment has allowed AR to integrate warehousing and manufacturing more quickly than other fields. Warehouse studies from DHL and Intel have shown that productivity has increased at least 25% and quality improved with the adoption of AR technology [9].

2.6 Electric Utilities

Electric utilities have many uses for AR technology, including the following (from EPRI reports 3002010514 and 3002009258):

- Viewing asset maintenance manuals
- Performing storm damage assessment or inspections
- Accessing asset information in the field
- Facilitating switching communications integrating work-order information flows
- Obtaining real-time system status validation
- Visualizing faults in the field
- Overlaying any data, such as weather or operational data, in the field
- Viewing and analyzing power quality data in the field
- Using the same technology in the control center as in the field devices

AR technology is predicted to increase productivity and safety in electric utilities [19]. As a result, EPRI and IEEE are working to improve user experience of AR.

2.6.1 EPRI

EPRI conducts research to benefit the public on the generation, delivery, and use of electricity. With respect to AR, EPRI's current work strives to improve efficiency and reduce error rate in the utility industry [8]. EPRI is collaborating with several key constituents, including electric utilities and AR suppliers [8, 55]. EPRI's work with utilities and other stakeholders uses the most up-to-date hardware that is suitable for utility work.

2.6.2 IEEE

IEEE sets standards for the electric industry and brings together the global engineering, computing, and technology communities [49, 56, 57]. IEEE is working to ensure that AR can reach its full potential and is attempting to protect intellectual diversity so that many AR ideas, prototypes, and versions can be available in a healthy competitive environment. This collaborative environment will assist companies with the most relevant information and resources [49, 56, 57].

2.6.3 Digital Manuals and Independence or Collaboration of Workers

Electric utilities have many jobs in which field workers maintain and repair hardware of varying age; as such, these jobs require workers to read manuals to ensure that workers are performing the correct procedures [6, 58]. AR can give workers of all ages access to digital manuals that describe task procedures for old (legacy) to newer equipment. Digital manuals will be particularly useful to younger workers who may not have knowledge of or experience working with legacy equipment [58]. Workers' quick access to information of integrated field force data in real time is extremely valuable [59].

The available access to digital data can enable workers to save time and work more independently [20] and to collaborate with other workers [3]. AR allows for communication with an expert through video sharing and interactive computer interfaces. "With AR a worker can pull up to a job site, don a pair of AR glasses, and have at their fingertips every piece of information necessary to perform their task. In some instances, they can connect live to a remote technical service agent to help walk them through particularly difficult activities" [58]. If a worker needed to confer with someone who was an expert, they could share what they were seeing and receive verbal directions or even visual cues overlaid on the equipment they are viewing [7].

In addition, the larger a project (such as large construction projects, like installing new transmission lines along roads), the greater the need for close collaboration among the designers, engineers, workers, and the customer [2]. Building Information Modeling (BIM) allows for each person on the team to collaborate with assembling digitally their part of the project [2]. This interactive teamwork approach could result in higher efficiency, prevent accidents, and save money [54].

2.6.4 Safety

Although efficiency and cost-savings are important, the safety of the workers is paramount with any type of AR [35, 56]. With the BIM approach, every person has access to all the data—and AR allows each person to double check others' work. This double checking can reduce errors and conflicts between systems so that fewer problems emerge during the construction [2]. AR also assists in training employees safely to operate heavy equipment, manage construction activities, operate cranes, or even plan underground infrastructure [19, 43, 59–62]. These projects concern the safety of many individuals as well as surrounding structures, such as underground cables [43, 62].

Other ways to ensure safety include training workers before they go out in the field. The ability to simulate experiences in a controlled environment before going out in the field can reduce user error and accidents and save time [62]. Using AR for indoor training and outdoor field work has the potential to create a safer work environment, increase employee satisfaction, and reduce costs resulting from accidents or injury.

2.6.5 Affordability

AR is becoming more affordable because of the availability of mobile devices and accessibility to the Internet and cloud data storage [19, 56, 59]. In addition, the lighter weights and smaller sizes of AR devices are improving user experience and allowing employers to purchase them for a greater number of workers [19]. The mobile devices also make it possible for AR to be used with tablets or smartphones provided by the employer or owned by the employees. Mobile devices effectively lower the cost of AR by obviating the need for hardware dedicated solely to AR use. The increasing affordability of AR makes it a feasible and realistic choice to carry out tasks in the electric utility field [19].

2.6.6 Electric Utility AR Issues

One of the main challenges facing AR implementation in the electric utilities field is the harsh field conditions resulting from weather or terrain [56, 63]. Locations of jobs change daily and therefore present various challenges, hazards, and environments. Different locations may affect the projection abilities of an AR headset, effectiveness of the AR computer, or the clarity of the eyewear. Extreme cold or heat and air particulate—such as sand—may diminish computer hardware function or legibility of text on projected materials [57, 63]. Moreover, there are human factors concerns for AR users, such as cognitive loading and situational awareness (including sense of time [64, 65]), and physical stressors such as neck pain and eye strain. These human factors issues are explained in the next section.

Table 2-5 lists uses of AR in industrial, manufacturing, and electric utilities.

Table 2-5
Augmented reality uses in industrial, manufacturing, and electric utilities

Device	Reference	Pros*	Cons*
ARTool Kit	(Chi, Kang, and Wang, 2013) [19]	● Low startup cost	● High monthly subscription fees ● Community is small and inactive
Atheer Air	(Stone, 2016) [55]	● Improved productivity, accuracy, quality, and safety of skilled industrial work force ● Manufacturing, construction, heavy industry, logistics, retail, medical, energy, and field technical services	● Problematic in loud environments ● Privacy concerns ● Distracting from the real world ● Unsuitable for remote video ● Problematic when handling equipment
DAQRI Smart Helmet	(Tilley, 2016) [8]	● Can measure physiological aspects of workers such as heart rate, skin temperature, blood oxygen levels, and frontal lobe activity (to monitor focus and cognitive states)	● Expensive ● Heavy (3 lb) ● Possibly overly invasive by measuring brain activity ● Cannot wear glasses under helmet
IOS Software: iPhone, tablet	(Stone, 2016) [55]	● ARKit Apple ● Uses visual inertial odometry to overly AR content on the real world within apps	● Competing with Facebook for AR community and apps
Nomad HMD	(Gabbard, Hix, Swan, Livingston, Hollerer, Julier, Brown, and Baillot, 2003) [35]	● Long-term usage ● Head-mounted display	● Uncomfortable ● Headaches ● Eye strain (sore eyes)
Osterhout Glasses (ODG)	(Economist, 2017) [7]; (Tilley, 2016) [8]	● For industrial and medical purposes Some upcoming products aimed at individuals ● High-quality display	● Expensive
Welding Helmet-TEREBES	(Park, Schmidt, Schlick, and Luczak, 2007) [66]	● Allows for welders to have a wider field of view than when wearing typical welding safety helmets	● Hand-eye coordination is not accurate

* Pros and cons were reported in the corresponding references.

3
REVIEW OF AR HUMAN FACTORS LITERATURE

3.1 Background

In the past, *ergonomics* has referred to the physical or physiological aspects of work while *human factors* described the cognitive and psychological aspects. In the recent past and present, the meanings have been blurred—the terms *human factors* and *ergonomics* generally embody both the physical and cognitive aspects of work and products. In this report, the terms *human factors* and *ergonomics* are used interchangeably.

Very limited tests have been done to measure the human factors aspects of AR devices, whether they are eyewear, head wear, HUD, or projected. In the past decade, research has looked at the challenges facing AR resulting from technology limits [64]. The majority of research on human factors issues addressed the functionality of the AR device: Does it work? Is there lag time? Is it effective? Is it useful? However, as the technology becomes more developed, improvements in functionality have reached the point that physical strain (muscle and eye), risk of injury, and safety can be addressed.

In the electric utility field, the human factors aspects of new technology address not only comfort and efficiency, but also safety [19, 36, 64]. Safety is paramount—it may at times affect life or death. With workers near high-voltage lines and sometimes having the responsibility of coworker's safety in job sites, the testing of AR devices for these individuals must be done. Following are descriptions of human factors studies of AR along with their results.

3.2 Cognitive Load and Situational Awareness

Human factors testing of AR devices can be for both physical and cognitive load on the individual [45, 66]. *Physical load* refers to the physical or physiological aspects of the device (for example, weight, visibility, and so on) but also the device's effect on muscles and joints of the body [3, 67]. *Cognitive load* refers to how AR technology makes adjustments in real time and how these changes affect the cognitive state of the individual, depending on the task. Cognitive variables are challenging to measure because of the many aspects particular to each individual and the difficulty in measuring indicators of mental states [68].

Cognitive overload looks at the psychological factors as well as the distractions from carrying out tasks [62, 65]. Using AR devices is considered multitasking and extremely stimulating because they use the visual senses in an immersive way [68]. With *situational awareness*, individuals are distracted from their surroundings and may endanger themselves or others as a result [64, 69]. An example of AR technology affecting situational awareness is when individuals were walking into the street to catch virtual creatures while playing Pokémon Go. Their lack of situational awareness from being so immersed in the game resulted in car accidents, and the game added warnings on the screen to make individuals aware of their surroundings [70]. Warnings such as "do not play Pokémon Go while driving" and "do not enter dangerous areas" are examples of how the app decided to address the users' lack of situational awareness [70]. When users are reading or receiving so much information, they may not be fully aware of their surroundings. Despite providing useful information to users, AR may be a distraction and therefore result in safety hazards. These concerns were tested on various devices according to reports in 2015 [49].

3.3 Development of Guidelines

Early research in the field of AR focused on the functionality of the device—for example, during AR's infancy, researchers were simply trying to find functionality of the AR devices, which required better technology than was available at the time [66]. Despite technology troubles, the researchers were concerned with the human cognitive performance "when information is presented via augmented reality (AR) and overlaid upon a primary display" [66]. As part of the study, a website was created that provided consolidated data to develop guidelines for future study with AR technology [66].

For many of these researchers, there was not a suitable framework to apply cognitive load in relation to AR devices [68]. As a result, many studies proposed their own framework and research methodology. One study in particular made a framework to create an adaptive AR that assessed an individual's environmental and cognitive state in real time [68]. This framework suggests that developers use an adaptive AR interface that reduces the amount of information to the user when they are experiencing a high workload. It then adjusts for the user during their low workload to present an appropriate amount of information. This helps reduce cognitive overload by taking into consideration the varied situations in which users employ their devices [68].

There is currently no clear recommended amount of time for use of AR devices, and each device normally results in differing amounts of time use before cognitive load occurs. Because AR is a fairly new technology, researchers are unsure of the long-term effects of daily employees use. Not only is there a lack of information surrounding the amount of time use for adults, there is a dearth of information for children—who may be extremely affected or swayed by the media on their perceptions of the world.

3.4 Situational Awareness in Military Devices

A study that explored cognitive strain and overload with combat military was concerned with situational awareness [33]. For individuals using AR in field combat, their reaction time could be life or death. An early military study found that the cognitive effects were either an overuse or underuse of the device, depending on the reliability of the software [33]. Although the AR device had the ability to make soldiers more aware, they may over-trust the device and relax their own situational awareness. Conversely, if individuals find fault with the device, they will choose not to use it, losing the opportunity for situational awareness [33]. Individuals may over-rely on automation, which is an issue not just in AR but with other new technologies.

In a study conducted nearly a decade later, AR technology had improved. The experimenter's task was to design strategies for presenting real-time situational awareness without distorting the individual's perception and senses [30]. The combat environments and challenges were taken into consideration in the design of the command- and tactile-controlled AR device and software, iLeader. The hope was to create a "heads-up, hands-free, finger-on-the-trigger" device [30]. The results showed that the iLeader user interface allowed for clear situational awareness. The device proved to be non-disruptive and extremely useful for field combat [30].

3.5 Driving Vehicles

Distraction is a possible consequence of using AR while driving. Research conducted at the University of Utah studied distraction from drivers using infotainment systems and smartphones. In one study, in-vehicle infotainment systems such as voice-dialing, voice-contact calling, and music selection caused driver distraction in ten 2015 model-year vehicles. Three vehicles were rated as moderately distracting, six as highly distracting, and one vehicle as very highly distracting [71]. This study also found that older drivers were at a greater risk than younger drivers for distraction and cognitive overload.

These authors also investigated how the use of hands-free voice commands to dial phone numbers, call contacts, change music, and send texts with Microsoft Cortana, Apple Siri, and the Google Now smartphone personal assistant affected driver distraction and cognitive load [72]. A major conclusion from this study was that hands-free smartphone devices caused high cognitive workload, which caused drivers to take up to 27 seconds to regain full attention on the road after disconnecting from the application. A residual delay of 27 seconds is the time required for a driver traveling 25 mph to cover the length of three football fields before regaining full attention.

In a study investigating a driver's cognitive control while using AR during driving [45], a proposed framework was tested. The results showed that AR did affect and impair variable driving tasks, whereas the automatic tasks were not affected in a negative way [46]. Therefore, the effects of cognitive load on driving depended on the tasks and on a case-by-case basis. The authors said that their proposed framework from the study will be useful for future research on real-world crashes and the influence of cognitive load [45].

Another study that focused on driving looked at situational awareness of hazards—specifically the driving abilities of elderly drivers along with their hazard perception [43]. The study evaluated how effective AR was at improving driving safety with elderly drivers because they are at an increased risk as a result of cognitive impairments. The research measured whether AR helped or hindered hazard perception with elderly drivers. Participants drove 1 hour in an interactive driving simulator. Some scenarios used AR to point to hazards on the roadside; others used no AR. The AR was helpful in the detection of low visibility objects. The study showed that AR may be useful for improving the safety of elderly drivers because of hazard detection and found that the AR assisted, and did not interfere, with driving tasks such as safe distance behind a lead vehicle [43].

3.6 Physical Strain

Physical strain refers to physical discomfort, pain, or injury resulting from carrying out tasks while wearing or using AR devices [36]. The ergonomic design of the devices, primarily the HMDs, has undergone experimentation to find the most comfortable and safe design for the headwear [36, 64, 73].

3.7 Neck and Back Strain

Whether an AR device is worn or viewed, there may be strain on the neck and back. The physical strain can range from soreness and neck pain to headaches or more severe problems. Many devices are currently bulky and heavy [3]; therefore, headwear devices should have the most appropriate shape, weight, and materials to ensure ergonomic comfort and safety [3].

Holding tablets or smartphones in front of one's face to view through the screen or camera can cause physical strain, particularly in the upper extremities [3].

3.8 Eye Strain

Use of AR may cause eye strain, which can be manifested by headaches or blurred vision or even delayed hand-eye motor coordination [3]. One of the causes of eye strain is the graphics superimposed on the AR device. AR superimposes graphics on a user's view of the real world; if these graphics are not clear or easy to read, AR loses its advantages.

Projected AR can be used effectively as an alternative to a monitor for displaying information. The legibility of projected text can be affected by color, environmental conditions, text style, material and shape of the surface being projected [64], and by tactile irregularities on the projection surface. In a 2015 study, the text legibility of projected AR on industrial workbench surfaces was investigated [64]. Sets of colors were projected onto several commonly used work surfaces. Qualitative interviews were conducted to seek feedback on the legibility on the various surfaces. An AR device improved the vision of colors, with the exception of blue; the AR device could be used in lieu of a traditional monitor [63].

Eye strain can also occur with head devices that do not fit the user well or where the graphics are not lining up with the user's sight lines. Hua and Gao [74] conducted a study that focused on a systematic framework for online calibration of a head-mounted projection display. AR is successful when it blends the real-world senses with the digital information overlay—a process described as *registration* [74]. When the sight line is not aligned with the projected graphics, misregistration occurs. Causes for misregistration include the helmet slipping or inter-pupillary distance not set accurately. AR technology may have to be custom-fitted on some users to achieve accurate registration [74].

Eye strain or limited viewing may cause problems with hand-eye coordination. One study investigated the design and evaluation of an AR welding helmet [65] by measuring the hand-eye coordination of welders and non-welders with two prototypes of AR welding helmets. The first prototype operated at 16 frames per second; the second, improved version had 20 frames per second. The measured variables were the hand-eye coordination of the welder or non-welder using the HMD with a see-through display vs. the natural vision of the welder or non-welder without a helmet. The results showed that HMDs should not be used in tasks that require precise hand-eye coordination and minute accuracy [65]. Problematic issues were displacement of cameras from the eye position, field of view, and time lag—which affected both the welders and non-welders.

4

AR HUMAN FACTORS KNOWLEDGE GAPS

4.1 Human Factors Knowledge Gaps

In the past decade, AR research has primarily focused on the functionality of the technology by looking at issues that were a result of the technology available at the time—and human factors testing was limited. Technology has now reached a point that researchers can focus on more advanced human factors in the fields of cognitive loading and physical strain. The following is a list of basic cognitive and physical aspects of AR devices that should be addressed.

4.1.1 Cognitive Loading and Situational Awareness

The workplace is often a more complex environment than the home because there are many more types of activities and equipment that can cause injury if one is not aware of them. Therefore, effects of AR technology on situational awareness must be studied rigorously before AR is deployed on a large scale in an industrial or commercial environment. Individuals must be able to perform basic ADL safely at work, such as walking, lifting objects, and maneuvering without hazards of slips, trips, and falls. The benefits of AR, particularly improvement in quality and efficiency of tasks, depend on a user's mastery of situational awareness.

In augmented reality, the quality of the projected display and the underlying software affects the user experience [64]. There are currently no industrywide guidelines for ensuring that AR devices do not cause cognitive strain or overload, and creation of measurable scales and a list of required design factors would benefit the entire AR industry. Organizations such as AREA are working on developing AR product guidelines [49, 51, 74]. The standardization of guidelines would be applied to a broad scope of devices rather than just one or two. These guidelines would enable AR developers to follow approved development guidelines for their devices.

4.1.2 Physical Strain

Current AR headwear tends to be bulky and awkward, which can create extra loading on the neck and shoulder muscles. There has been limited research on the effects of AR technology on neck and back strain. These strains are a serious concern related to AR headwear and handheld devices because they may require awkward postures of the head, neck, and upper extremities. Furthermore, the amount of time that employees will use AR will most probably increase in the future and may exacerbate neck and back strain.

No literature could be found reporting measurement of muscle loading from wearing AR devices. To address this concern, EPRI is conducting a study of an AR headset for electric utility workers in which electromyography (EMG) recordings of the neck and upper back muscles will be measured and compared to muscle loading without AR headgear. Muscle loading will be input into fatigue models to estimate the amount of time that users can wear an AR device comfortably and with minimal risk of a musculoskeletal disorder.

4.1.2 Eye Strain

A few studies investigated graphics effects on the eyes. To minimize eye strain, more tests are needed to determine the maximum amount of time that workers should wear AR devices (there are no guidelines on this currently). Future studies should test various types of devices, glasses, displays, smart devices, and projected visuals [3]. One aspect that must be investigated is the registration of the visual display to the sight lines of the user. Misregistration will hinder a user's view of the environment and may cause eye strain and poor coordination of arm and hand movements.

4.2 The Future of AR

AR is continually improving as new technologies become available and more affordable. Future versions of AR will augment more human senses than just the visual and will incorporate more sensory and perceptual sensors [1, 2]. Future human factors studies should focus on new and emerging forms of AR technology in addition to the basic human factors research gaps noted previously. Examples of emerging AR technology include IoT, smart clothing, eye control, and consciousness.

4.2.1 Internet of Things

Society is moving toward the IoT, where even our refrigerators are connected to our phones and a voice-activated computer can control our air conditioning (AC) in our homes [1]. The IoT refers to a world "where sensors and actuators are embedded into physical objects and are linked through the wireless and wired networks that all live and interact with one another" [1]. The IoT will be used to collect vast amounts of information and analyze the data through the tracking of individual behavior, creating further enhanced situational awareness and providing sensor-driven analytics [1]. AR may be useful for enabling situational awareness through interaction with sensors in buildings and roads [1], making individuals hyper-aware of their surroundings.

As more products become connected to the IoT, AR may become a standard device for interacting and receiving data from these online devices. With the expansion of IoT, the human factors issues of cognitive loading—particularly from expanded situational awareness—and biomechanical loading from AR devices must be tested to ensure that people can use the technology safely and comfortably.

4.2.2 Eye Control

In response to the bulkiness and obtrusion of current AR devices, AR contact lenses are being developed and tested [2]. Contact lenses will diminish neck and back pain compared to the present AR hardware. Already a large segment of the population wears contact lenses, and developers anticipate that AR lenses will be a popular choice for consumers [2]. Whether for glasses, helmets, or contact lenses, the placement of the visual overlays must not obstruct the user's view of the environment.

A new software called *Eyefluence* enables the eyes to control the placement of overlaid images in the field of view. Eyefluence can change the apps on the visual field and allows eye movement to control the computer [75]. These devices have progressed quickly and effectively over the past few years, and progress is expected to continue. Eyefluence, along with the possible use of AR contact lenses, may play a large role in the future of AR [1]. For this reason, more research on human factors must be done to ensure that eye control does not cause eye fatigue, or worse, damage to the field of vision [75].

4.2.3 Smart Clothing

The military currently has AR headsets that collaborate with smart clothing; this technology is expected to be integrated into the general consumer market. With smart clothing, users can use gestures to manipulate images with their hands, or their movements can be registered as digital information and shared with others [75]. The sensors in smart clothing may make AR more useful for various fields and possibly for electric utilities [3].

The tactile and force feedback abilities of AR integrated into smart clothing will make it possible to move, touch, and alter images over the real world [2]. Coordinating the overlay images and manipulating them to fit the needs of the moment and the location within the real world will be useful for employees who work in the field and have variable tasks in their daily work. Human factors research in the cognitive and biomechanical fields must be integrated into every step of development of AR integration into smart clothing to ensure the safety, occupational health, and comfort of users—particularly because of the long duration that smart clothes will be worn.

4.2.4 Effects on Consciousness and Social Interaction

Both VR and AR intimidate some people, and some studies show that prolonged exposure can create confusion mentally because our bodies are not used to having to differentiate between the real and digital worlds [2]. Therefore, the merging of these two worlds into consciousness is a concern. However, AR—unlike VR—is rooted in the real-time, real-world environment with only digital images superimposed, which may help users remain grounded consciously [2]. Cognitive research is needed to determine these effects.

There may also be social repercussions from the widespread use of AR. Self-isolation and lack of interaction is a concern with the future of technology [75]. Anecdotal observations of the general population using smartphone technology indicate a reduction of social interaction. If individuals are wearing AR technology 24/7 in the future, this effect may be amplified. The impact of AR on social interaction is yet to be known, and human factors research must be conducted to make sure that humans maintain their social interactions—regardless of the type and pervasiveness of AR technology.

5 CONCLUSIONS AND RECOMMENDATIONS

Augmented reality is a technology that combines real and virtual information presented in an interactive way in real time. AR presents digital information to a user in the real world through tablets, smart glasses, headsets, and helmets. AR has devices in many fields—entertainment, education, navigation, military, industrial, and electric utilities. AR is growing rapidly and will likely be used by a significant percentage of the work force in the next 10 to 20 years.

There is a paucity of human factors and occupational safety research for AR devices in industrial settings, including the electric power industry. Important human factors and safety issues are physical strain (force of the neck and back muscles), cognitive loading, eye strain, and situational awareness. Studies that have investigated these issues have been generally preliminary in nature and have focused on the functional aspects of AR technology by addressing whether the technology works as intended. These studies have not yielded results that provide a deep understanding of how AR affects human factors and safety issues. Following are some of the limitations of the current knowledge of AR:

- The effect of the large, and sometimes heavy, head-mounted AR devices on the loading of the neck and upper back muscles has not been quantified. Muscle loading along with inertial properties of the head-mounted gear (weight, center of mass, and moment of inertia) can provide insight into how long a user can wear the gear without muscle fatigue or soreness.
- Studies of cognitive loading from AR systems have been piecemeal and have not used a general framework for a cognitive model that can be applied to a variety of AR devices.
- No studies have measured the factors that indicate eye strain—that is, blink rate and pupil diameter—in AR devices for electric utilities. Eye strain can lead to headaches and poor situational awareness.
- The effects of AR on users' situational awareness, such as activities of daily life (for example, walking, climbing a ladder) have not been measured in electric utility tasks. AR systems may interfere with a worker's sensory perception, exposing a worker to risk of an acute injury.
- Researchers do not know the long-term effects of employees' use of AR devices daily for sustained periods of time. Guidelines for the appropriate amount of time for safe and effective AR usage are lacking.

Future studies of AR devices not only in electric utility work but also in industrial work in general should explore these human factors and safety issues in depth. Utility personnel must consider the fact that just because a technology is available does not mean that the technology is safe and without risks including acute and cumulative (ergonomic) injuries. It is particularly important for utility personnel to study the possible negative effects of AR technology because of the potentially hazardous work environments of utility workers.

The negative consequences of AR technology employed prematurely, without deep understanding of human factors and safety issues, may differ depending on the field of use and application. Although AR may be beneficial to workers by, for example, improving performance and quality of work, the unintended consequences of AR must be explored thoroughly. Examples of unintended consequences for a worker include the following:

- Cannot walk or climb stairs safely while using an AR system
- Is distracted by the AR-superimposed graphic displays and touches the wrong cables, exposing him or her to electric shock
- Becomes distracted or overloaded cognitively with AR displays and cannot place enough attention on the task to perform it safely
- Develops fatigue in neck muscles, reducing reaction time and coordination of arm and hand movements
- Develops a headache or blurred vision from eye strain

AR is evolving rapidly, and its form factors will become smaller, less cumbersome, and more pervasive. Examples of future forms of AR are contact lenses (which may replace head-mounted gear), smart clothing embedded with AR devices, and AR devices embedded in the IoT. A deep understanding of how these future forms of AR will affect human factors and safety issues is imperative before AR is integrated into electric utility field work.

6
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