Industrial application of augmented reality

ISHII Hirotake[1]

1. *Graduate School of Energy Science, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto-shi, Kyoto 606-8501, Japan (hirotake@ei.energy.kyoto-u.ac.jp)*

Abstract: Recent progress in tracking technology can be a breakthrough for the introduction of augmented reality into industrial fields. Various applications proposed in the past that have not been put into practical use can be re-implemented with new tracking technology. Different capabilities and expectations might induce a very rapid introduction of augmented reality into industrial fields and might change daily life dramatically. In this article, after a brief introduction of augmented reality, past industrial application proposals and trials of augmented reality in the field of aviation, architecture, automotive, maritime, and nuclear are reviewed. Then future trends are predicted.

Keywords: work instruction; application trend; aviation; architecture; car, maritime; nuclear

1 Introduction

More than 50 years have passed since Prof. Ivan Sutherland developed "The Sword of Damocles," which is now regarded as the first augmented reality (AR) head mounted system in which computer graphics are superimposed over a user's view according to the user's current position and orientation to enhance the user's perception [1]. Since then, AR has gathered much interest [2, 3]. It is expected to have strong effects in various fields such as education, entertainment, medical, military, and industry. Although many studies and developments have been conducted, only a few outcomes have been put into practical use [4, 5]. Mass media have published numerous news and reports related to AR in the 2000s, but that enthusiasm has long gone. AR came to be regarded as scientific fictions. However, as in Gartner's report of the hype cycle for emerging technologies [6], AR just passed its peak of inflated expectations around 2014 and currently arrives at the bottom of valley before its secondary boost. In the past few months, large information and communication technology (ICT) companies such as Apple and Google shipped AR development kits that provide high-performance tracking technology [7, 8]. By virtue of these new development kits, which are useful by everyone who has a basic skill of programming, a high possibility exists that AR spreads widely in various fields extremely quickly and that it changes our daily life dramatically. It is time to revisit past proposals and trials of AR application because these applications have become much easier to realize than ever before.

This article presents a brief introduction of AR in chapter 2. Then past proposals and trials to apply AR to industrial fields such as design, assembly, maintenance, repair, and decommissioning of aircraft, buildings, cars, ships, and nuclear power plants are reviewed. Finally, future trends are predicted.

2 Brief introduction of augmented reality

AR is a human-computer interface design strategy intended to enhance a user's visual perception by superimposing computer graphics over a user's view. The computer graphics are aligned automatically with real objects when the user's position and orientation are changed so that the computer graphics seem to be depicted in the real world. When the superimposed computer graphics are three-dimensional virtual objects, the user can feel as though these virtual objects actually exist in the real world. Figure 1 presents examples of visual augmented reality where the user can see both computer graphics and the real world simultaneously. Actually, AR has three main distinguishing features compared to conventional interfaces [9]:

1. AR can show a three-dimensional position and orientation in the real world intuitively.
2. AR can make invisible information visible.
3. AR can simplify comparison of real objects and three-dimensional models.

Received date: September 20, 2017

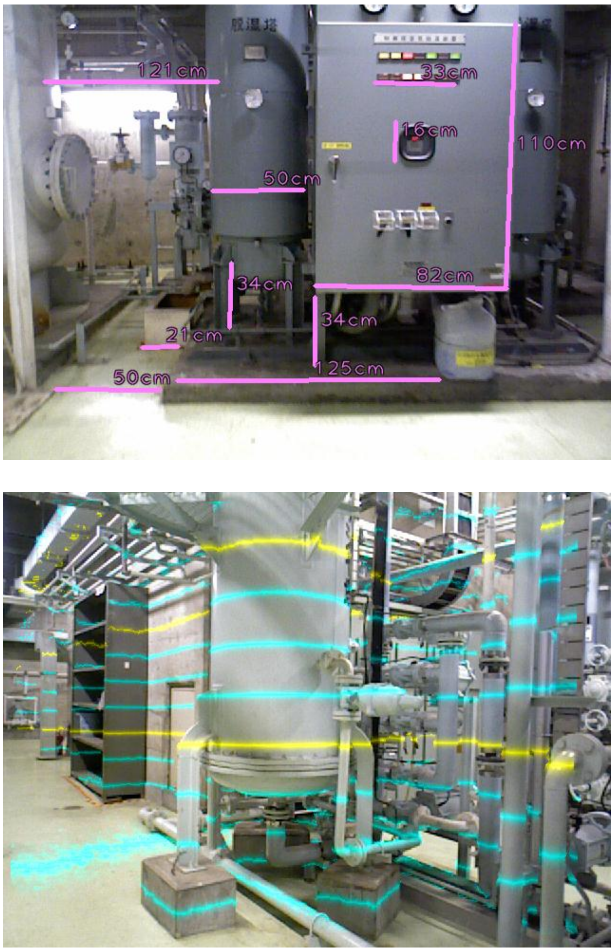

Fig. 1 Examples of visual augmented reality at Fugen Decommissioning Engineering Center. Metric information is superimposed over camera images. (Top) Length and distance visualization. (Bottom) Height visualization. In both cases, the metric information is obtained using an RGB-D camera, which can capture both color and depth images simultaneously.

By virtue of these features, it has been anticipated that AR is applicable to various industrial fields to increase efficiency and safety. However, the actual introduction of AR to industrial fields has not been promoted as expected. That is true mainly because elemental technologies that are indispensable to develop AR-based application has not matured.

To develop AR-based applications, various technologies are necessary. Especially, tracking technology [10] and display technology [11] are important: they affect the quality of AR-based applications. Tracking technology measures a user's current position and orientation in real time. The result is used to decide how computer graphics are drawn. The display technology, mainly hardware technology, shows the user images with superimposed computer graphics.

Although numerous studies of tracking technology have been conducted in the last two decades [12-15], none can realize an ultimate tracking technology that is useful for all kinds of environments with sufficient accuracy and reasonable cost. For example, marker-based tracking can provide accurate tracking, but the costs of preparation and maintenance are too great for practical use. Marker-less tracking and inertial sensor-based tracking, respectively, lacks stability and accuracy. However, because of recent advancements in inertial sensors and processing units, it has become possible to realize very accurate and stable tracking at reasonable cost. In principle, the inertial sensor is stable and fast, but it is unfortunately prone to accumulate drift errors. By contrast, camera-based tracking, which requires fast processing unit, is extremely accurate and free of drift errors, but is vulnerable to environmental change. High-performance tracking has been achieved by combining the respective advantages of inertial-sensor-based and camera-based tracking.

Various displays have also been developed during the last three decades. They are classifiable into several categories: head mounted displays (HMD) [16], handheld displays [17], and projection displays [18]. It is widely regarded that HMD is the best display for AR because users can use both hands while watching superimposed images. However, that is true only if HMD fulfills conditions such as being lightweight, having a wide field of view for both real environment and computer graphics, and being free of problems related to fatigue or sickness, even when used for long periods. Many companies have shipped various HMDs, but they were not specialized for AR. Most were developed for entertainment purposes. Therefore, most HMDs lack cameras, wireless communication capabilities, high-performance processing units, and input methods that are necessary to develop AR-based applications. The Google Glass [19] HMD has all of these additional functions, but, it has some shortcomings: The field of view for computer graphics is narrow. It is difficult to align computer graphics to real objects accurately because the HMD is optical see-through. The input interface is difficult to use. Moreover, although it is extremely lightweight, users feel uncomfortable. Unfortunately, a suitable HMD for AR is still unavailable. However, this is not expected to hinder the expectations of rapid introduction of AR into industrial fields because not all industrial application requires workers to conduct work while watching superimposed images. The handheld display is a reasonable runner-up for use with industrial AR because most work can be conducted without watching instructions after workers understand them. Moreover, it is easy to switch from “in use” to “not in use,” and vice versa using the handheld display. Therefore it would be sufficient if workers were to hold a handheld display before their work starts to see the superimposed instructions. Then the display could be put away into baggage or hung on the waist with a strap. Moreover, the handheld display presents many advantages over HMD: it has a touch user interface with younger people are now very familiar. It can provide higher resolution images and higher performance processing units than HMD can. Moreover it has wireless communication as a default.

The effectiveness of AR has been demonstrated through several subjective evaluations [20, 21]. The main obstacle to introducing AR into industrial fields is the difficulty of developing reliable, user-friendly and low-cost AR applications. These difficulties have been almost entirely resolved by re-implementing AR application using newly emerging tracking technologies and handheld displays instead of HMD.

3 Past industrial application of augmented reality

Actually, AR can support design, assembly, maintenance, repair, decommissioning, and other applications. Applications of various kinds have been proposed and developed for aviation, architecture, automotive, maritime, and nuclear fields. Some examples are reviewed hereinafter.

3.1 Aviation

Assembly and maintenance of aircrafts is a promising industrial field to which AR is applicable because even a small error might entail severe difficulties that can put human life at risk. Therefore, it is worthwhile to reduce errors to the greatest degree possible. Investing time and funds into building models of aircraft mechanical parts is economically reasonable because multiple aircraft are usually built using the same design; the same models can be reused. The models are used for various purposes such as producing instruction contents and model-based tracking. Among the first application of AR was realized by Boeing Corp. during the late 1980s [22]. They developed a special headset by which the direction of an electrical wiring harness is shown to workers by superimposing a drawing over a workers’ view. Most of the recent AR application in the aviation field use three-dimensional animations to illustrate how to assemble and inspect mechanical parts of an aircraft [23] and to investigate how to make the application more intelligent to provide adequate information to workers according to the worker circumstances and environment [24-26].

Also AR is applicable for navigation of pilots to destination airports or visualization of a landing runway during poor visibility because of bad weather. After landing, AR can display the taxiway the aircraft should follow [27, 28]. Hardware used for pilot navigation can heavy and expensive. The crucially important point of the system is its accuracy and reliability. Special hardware such as a laser gyro sensor and head-up display, rather than inexpensive camera-based tracking and HMDs, are used to realize the system.

3.2 Architecture

In the architecture field, AR is applied mainly to the exterior and interior design of buildings.

For exterior design, AR is useful for consensus building among residents related to the effects of landscape change. The new building design is superimposed over existing buildings. The harmony among them can be verified in advance more intuitively than when using the conventional method such as hand-drawn sketches [29-31].

For interior design, AR is useful to investigate the furniture layout and room makeover [32]. The room interior can be assessed by placing virtual furniture aligned to real walls or existing furniture. It is even possible to remove existing furniture or replace it with virtual furniture using a diminished reality technique [33, 34], which superimposes a virtual wall or floor over existing objects to eliminate them visually. Many techniques are applied to make the visual distinction between virtual and real as small as possible so that we can feel as if the existing objects are removed from the room completely.

AR is also useful for checking discrepancies [35, 36] and for monitoring the progress of construction [37]. By superimposing the as-planned building model over an as-built building, the differences between them can be ascertained easily.

For architecture, introduction of IT technologies has been promoted actively for many years as Building Information Modeling (BIM). A foundation to provide contents for AR has already been established. Therefore, the architecture field can be the first in which AR is used widely, benefiting from recent advancements in tracking technology.

3.3 Automobiles

For both car design and driving navigation, AR is useful. Not only the exterior design of cars but also the interior design can be investigated using AR. One earlier report [38] describes a design prototype of a car dashboard superimposed over a simple mockup on which details such as handles, meters, and control buttons are not implemented. Designers can modify the design with no physical change. They can even change the handle layout from right to left. A prototyping system of this kind is extremely useful for the early stages of car design.

Driving navigation is a traditional application target of AR. Many related studies have been conducted in the past [39-41]. For this application, safety is of paramount importance. Therefore video-see-through HMD cannot be used because HMD of this type might intercept the driver’s view when broken. For that reason, most prototypes use head-up display instead of a HMD. The navigation contents can be arrows showing the direction in which to go, lane markings to convey message to drivers, and marks of attention, indicating potential hazards such as pedestrian and bicycles. Benefits of using AR to navigate drivers are that drivers need not take their eyes off of the road and that navigation can be more intuitive. Drivers can therefore devote more attention to the driving itself.

Furthermore, AR can realize a pseudo-transparent car. As described in one report [42], the car interior is covered with retroreflective material. Cameras placed outside of the car reveal objects in the driver’s blind spot. The captured live video is projected over the retroreflective material in an optically conjugate manner so a driver can view the surroundings with no blind spot as though the car were transparent. This technique can reduce traffic accidents, which are often collisions with objects in the driver’s blind spot.

3.4 Maritime

Supporting workers using AR is also useful for the assembly of ships. Welding is an important skill by which metal pieces are integrated into a single large metal object that might be difficult to cast directly. Welding is also useful to deform metals to produce complex parts such as them stem of ship. However, mastering welding skills is extremely difficult and time-consuming. To support welding process, the welding position can be shown intuitively by superimposing the position to which a welding gun should approach [43, 44]. The time span that the welding gun should be kept there can also be presented intuitively.

Ship navigation is also a possible application of AR in the maritime field. Sometimes ship pilots encounter difficulty perceiving surroundings such as approaching ships and coasts when weather is bad or at night. Even with good weather, perceiving water depth is difficult when sailors are not familiar with the visiting area. One report if the literature [45], proposes an AR-based navigation system in which the water surface is painted in different colors to portray water depth. The tide against the ships is shown by superimposed allows. Relations to the other ships are also shown using AR.

3.5 Nuclear

AR can show the three-dimensional position and orientation so that it can be understood by users very intuitively. Therefore, field worker support at nuclear power plants is a promising application of AR.

Navigating field workers using AR is a traditional possible application of AR that can shorten the time necessary to reach a workplace and avoid errors caused by accidental worker manipulation of wrong instruments that might closely resemble others. One report of a study [46] proposes an AR-based support system in which AR is used to show the direction and position of the target valves to make it easy for field workers to find them in an environment crowded with similar valves.

Also, AR provides the capability of making radiation fields visible to field workers. One report of the relevant literature [47] describes a radiation field visualized with colored three-dimensional mesh, as shown in Fig. 2, with which field workers can understand the radiation distribution intuitively. It becomes easy to imagine which route is the best one to follow to minimize radiation exposure.

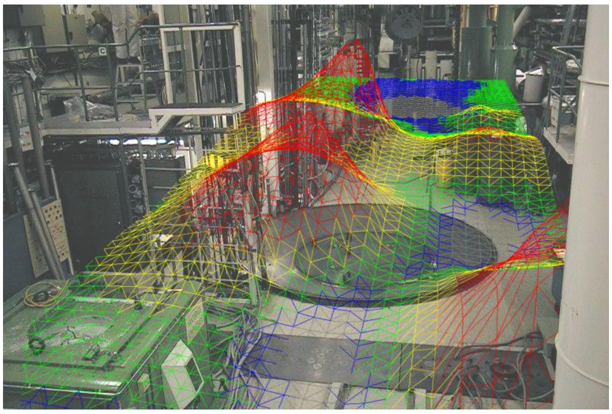

Fig. 2: Radiation map visualization using AR [47].

Decommissioning of nuclear power plants is much different from the decommissioning of non-nuclear plants or buildings because of the possibility of radiation contamination. Detailed procedures of the decommissioning are planned in advance. Workers must follow procedures strictly one-by-one. Using AR, the instructions for the procedure task can be provided more intuitively than when using conventional methods such as paper-based documents [48]. By contrast, in nuclear power plants, the available space for decommissioning work is limited. Therefore, space management is also important. Because of the recent advancement of modeling technologies such as simultaneous localization and mapping (SLAM) [49], it is much easier than ever to obtain three-dimensional surface models of the working environment, as shown in Fig. 3. Surface models are useful to investigate space availability for dismantling work such as the conveyance and temporal placement of dismantling wastes. One report of the relevant literature [50] describes the conveyance of dismantling wastes as simulated on-site using AR to confirm that no collision will occur between the conveyance target and narrow passage. Figure 4 shows that the collided parts between the conveyances target and passages are virtually shaded in red.

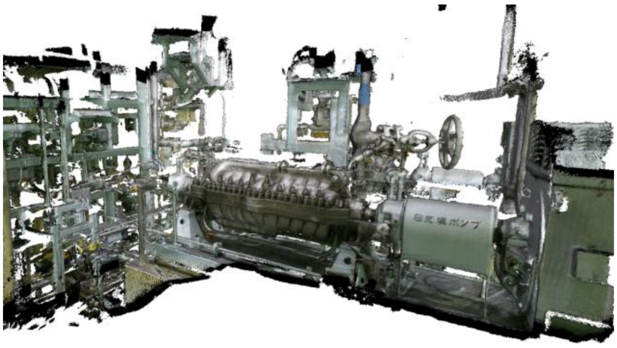

Fig. 3 Surface model obtained using RGB-D camera and Simultaneous Localization and Mapping.

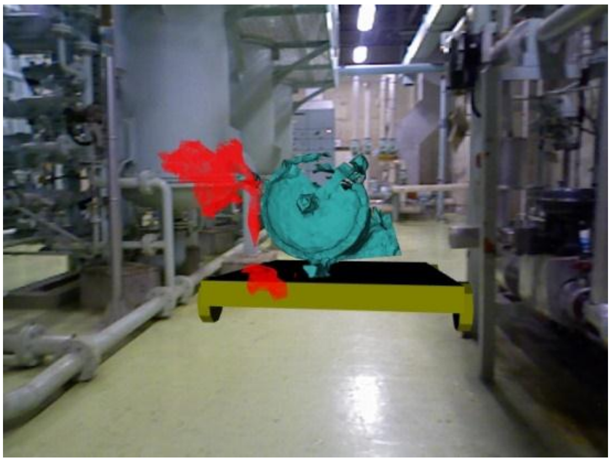

Fig. 4 Conveyance simulation using AR.
The collided parts between virtual tank and real passage are shaded in red. Three-dimensional surface model of the passage is obtained in advance using simultaneous localization and mapping (SLAM) technology.

The surface model can also be used to ascertain and depict a layout of dismantling wastes. By virtue of the detailed color model of environment, the layout can be found without visiting the site so that the possibility of radiation exposure can be reduced. Figure 5 depicts an example of using detailed color model of dismantling environment to decide the layout of dismantled wastes. The planned layout can be shown to workers on-site using AR intuitively.

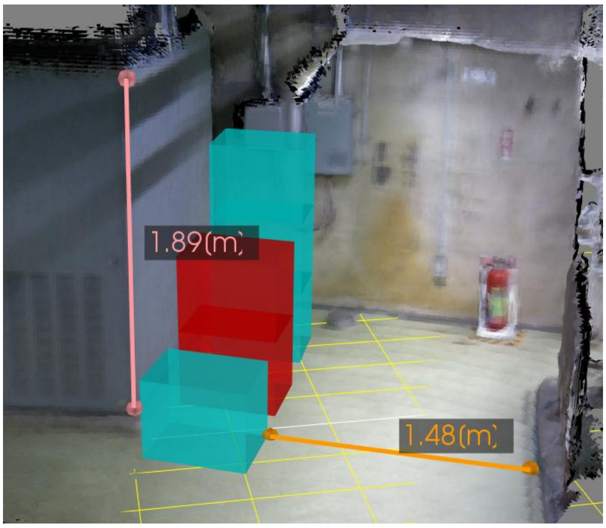

Fig. 5 Planning a layout of dismantled waste using detailed color model of environment.

4 Past and future trends of work instruction

Methods of instructing field workers have been changing along with the progress of ICT. Figure 6 shows that past and possible future trends of work instruction can be regarded as a generation change.

The first generation is a paper-based document that is used even today in modern plants. Instructions are written on paper with text and figures. Complex procedures are sometimes presented with two-dimensional figures that are difficult to understand and which might lead to miss-understandings. Apparently, the amount of information accompanying the paper-based documents is limited. Therefore, workers must rely to some degree on their knowledge and past experience.

The second generation is a tablet-based electronic document for which the amount of information accessible on-site is not limited and by which useful functions such as keyword search are available. Devices of this type have already been introduced for use at some non-nuclear plants, where they are regarded as useful. Multimedia such as videos of past maintenance can be viewed on-site, which is expected to be a great help, especially for novice workers. However, the interface of the conventional tablet-based electric document can be a source of inefficiency. They must understand the documents first and then find the target in the real environment. This comparison and search task is time-consuming. Moreover, it might lead a miss-operation when many similar appearance components exists in the plants.

The third generation is AR-based procedure task instruction. The work instruction is shown over the worker's view with its position aligned with the instruction target. The superimposed instructions mainly represent the procedures of work with the position to which workers should devote attention, how to operate the target, and additional information related to the target. This style of work instruction is more intuitive and easier to understand than either the first or second generation. However, the workers themselves must choose the contents. This selection requires a certain degree of worker experience.

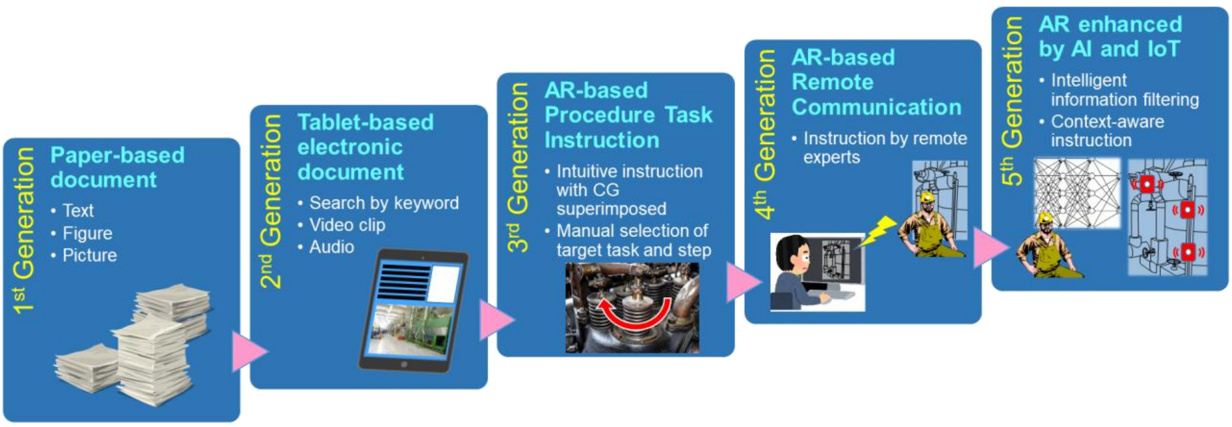

Fig. 6 Generations of work instruction.

The fourth generation is AR-based remote communication which has attracted active investment by ICT companies in recent years [51-53]. Field workers have a camera on their helmet, from which live video is streamed to remote experts who can watch the live video and provide instructions using drawings such as text and figures. The drawings are superimposed over the worker's view. Recently available systems can estimate the three-dimensional position and orientation of the camera in real time. The drawings' position on the workers view is adjusted automatically as if the drawings are fixed at the certain position in the working environment three-dimensionally. It is useful to present three-dimensional positions and orientations remotely. However, this work instruction is unavailable when remote experts and high-speed networks are unavailable. The ideal work instruction will be one that is always available when necessary.

The fifth generation is expected to be AR-based instruction enhanced by artificial intelligence (AI) and internet of things (IoT). An all-around agent able to support workers as portrayed in science fiction movies will not be realized in the near future. However, the possibility of AI, especially of deep learning techniques, should not be underestimated. Deep learning, which is one technique adopted for machine learning, is very powerful for generalizing a large amount of complex observations and deriving useful judgements from new observations. Especially, with the state-of-the-art of the deep learning, it is already possible to build a network that can recognize the position, category and status of objects from their appearance and internal data obtained by IoT devices if large numbers of labeled observations are available for learning.

In the near future, it will become possible to provide work instructions superimposed over a worker's view based on a similarity comparison between the current case and past cases. It will also become possible to give superimposed warnings by recognizing the surrounding environment as captured by cameras. Moreover, appropriate instructions will be given to workers at the appropriate position and appropriate timing according to a worker's position, work progress, and recognized abnormalities. Workers need not make any decision by themselves anymore.

As recognized widely, development of machine learning is continuing incessantly. Moreover, the cost of storage media is expected to drop. The number of cores on a processing unit will increase continuously, which is expected to lead to further performance improvement of machine learning. Here, the important point is that training a new network from scratch requires much time and money. However, once trained, the network is useful even with low-performance computers. Therefore, also from an economic perspective, it would not be difficult to introduce AR-based instruction enhanced with AI.

6 Conclusions

This article reviewed past application proposals and trials of industrial AR, with prediction of future trends. Expectations of new technologies will rise and fall, as they do with artificial intelligence. Apparently AR follows the same hype cycle but the recent progress of tracking technology might make great strides to practical use in industrial fields. Also generational changes of workers are expected to promote AR introduction because younger people are familiar with games, smart phones, and touch interfaces, showing strong interest in new technologies.

The introduction of AR enhanced with AI might lead a situation in which workers need not to learn anything anymore. Anyone can conduct tasks with no difficulty because of the intelligent instructions. One need only follow the instructions given by computers. Such circumstances will render humans as similar to robot actuators controlled by computers, which merely provide driving force with no applied intelligence. Such circumstances might be acceptable if objective tasks can be completed with no trouble. However, we might need a sixth generation of work instruction that is more intelligent so that workers can master skills for a task effectively while relying on the instructions for use during times when intelligent instruction is unavailable.

References

[1] SUTHERLAND, I.: The Ultimate Display, Proceedings of the International Federation of Information Processing Societies, pp. 506–508, 1965.

[2] AZUMA, R., BAILLOT, Y., BEHRINGER, R., FEINER, S., JULIER, S., and MACINTYRE, B.: Recent Advances in Augmented Reality, IEEE Computer Graphics and Applications, Vol. 21, No. 6, pp. 34-47, 2001.

[3] ZHOU, F., DUH, H., and BILLINGHURST, M.: Trends in Augmented Reality Tracking, Interaction and Display: A Review of Ten Years of ISMAR, Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality, pp. 193-202, 2008.

[4] ECHTLER, F., STURM, F., KINDERMANN, K., KLINKER, G., STILLA, J., TRILK, J., and NAJAFI, H.: The Intelligent Welding Gun: Augmented Reality for Experimental Vehicle Construction, Virtual and Augmented Reality Applications in Manufacturing, pp. 333-360, 2003.

[5] WETZEL, R., MCCALL, R., BRAUN, A., and BROLL, W.: Guidelines for Designing Augmented Reality Games, Proceedings of the 2008 Conference on Future Play: Research, Play, Share, pp. 173-180, 2008.

[6] GARTNER INC.: Gartner Hype Cycle for Emerging Technologies, 2017, http://www.gartner.com/ smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017, (Accessed September 1, 2017).

[7] APPLE INC.: ARKit, https://developer.apple.com/arkit/, (Accessed September 1, 2017).

[8] GOOGLE INC.: ARCore, https://developers.google. com/ar/, (Accessed September 1, 2017).

[9] ISHII, H.: Augmented Reality: Fundamentals and Nuclear Related Applications, International Journal of Nuclear Safety and Simulation, Vol. 1, No. 4, pp. 316-327, 2010.

[10] AFIF, F., BASORI, A., and SAARI, N.: Vision-based Tracking Technology for Augmented Reality: A Survey, International Journal of Interactive Digital Media, Vol. 1, No. 1, pp. 46-49, 2013.

[11] HAINICH, R., and BIMBER, O.: Displays: Fundamentals & Applications Second Edition, A K Peters/CRC Press, 2016.

[12] NAIMARK, L., and FOXLIN, E.: Circular Data Matrix Fiducial System and Robust Image Processing for a Wearable Vision-inertial Self-tracker, Proceedings of the 1st IEEE/ACM International Symposium on Mixed and Augmented Reality, pp. 27-36, 2002.

[13] KLEIN, G., and MURRAY, D.: Parallel Tracking and Mapping for Small AR Workspaces, Proceedings of the 6th IEEE/ACM International Symposium on Mixed and Augmented Reality, pp. 225-234, 2007.

[14] NEWCOMBE, R., LOVEGROVE, S., and DAVISON, A.: DTAM: Dense Tracking and Mapping in Real-time, Proceedings of the 2011 International Conference on Computer Vision, pp. 2320-2327, 2011.

[15] NEWCOMBE, R., IZADI, S., HILLIGES, O., MOLYNEAUX, D., KIM, D., DAVISON, A., KOHLI, P., SHOTTON, J., HODGES, S., and FITZGIBBON, A.: KinectFusion: Real-Time Dense Surface Mapping and Tracking, Proceedings of the 10th IEEE/ACM International Symposium on Mixed and Augmented Reality, pp. 126-136, 2011.

[16] KIYOKAWA, K.: An Introduction to Head Mounted Displays for Augmented Reality, Emerging Technologies of Augmented Reality Interfaces and Design, pp. 43-63, 2007.

[17] WAGNER, D., and SCHMALSTIEG, D.: Handheld Augmented Reality Displays, Proceedings of IEEE VR 2006 Workshop on Emerging Display Technologies, pp. 35-36, 2006.

[18] BIMBER, O., and RASKAR, R.: Spatial Augmented Reality: Merging Real and Virtual Worlds, A K Peters/CRC Press, 2005.

[19] REHMAN, U., and CAO, S.: Augmented-Reality-Based Indoor Navigation: A Comparative Analysis of Handheld Devices Versus Google Glass, IEEE Transactions on Human-Machine Systems, Vol. 47, No. 1, pp. 140-151, 2016.

[20] TANG, A., OWEN, C., BIOCCA, F., and MOU, W.: Comparative Effectiveness of Augmented Reality in Object Assembly, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 73-80, 2003.

[21] HENDERSON, S., and FEINER, S.: Exploring the Benefits of Augmented Reality Documentation for Maintenance and Repair, IEEE Transactions on Visualization and Computer Graphics, Vol. 17, No. 10, pp. 1355-1368, 2011.

[22] CAUDELL, T., and MIZELL, D.: Augmented Reality: An Application of Heads-up Display Technology to Manual Manufacturing Processes, Proceedings of the 25th International Conference on System Sciences, Vol. 2, pp. 659-669, 1992.

[23] CRESCENZIO, F., FANTINI, M., PERSIANI, F., STEFANO, L., AZZARI, P., and SALTI, S.: Augmented Reality for Aircraft Maintenance Training and Operations Support, IEEE Computer Graphics and Applications, Vol. 31, No. 1, pp. 96-101, 2011.

[24] JO, G., OH, K., HA, I., LEE, K., HONG, M., NEUMANN, U., and YOU, S.: A Unified Framework for Augmented Reality and Knowledge-Based Systems in Maintaining Aircraft, Proceedings of 26th Innovative Applications of Artificial Intelligence Conference, pp. 2990-2997, 2014.

[25] GOLAŃSKI, P., PERZ-OSOWSKA, M., and SZCZEKALA, M.: A Demonstration Model of a Mobile Expert System with Augmented Reality User Interface Supporting M-28, Journal of KONBiN, Vol. 31, No. 3, pp. 23-31, 2014.

[26] CUSANOA C., and NAPOLETANO P.: Visual Recognition of Aircraft Mechanical Parts for Smart Maintenance, Computers in Industry, Vol. 86, pp. 26-33, 2017.

[27] MOLINEROS, J., BEHRINGER, R., and TAM, C.: Vision-based Augmented Reality for Pilot Guidance in Airport Runways and Taxiways, Proceedings of the 3rd IEEE International Symposium on Mixed and Augmented Reality, pp. 302-303, 2004.

[28] FOYLE, D., ANDRE, A., and HOOEY, B.: Situation Awareness in an Augmented Reality Cockpit: Design, Viewpoints and Cognitive Glue, Proceedings of the 11th International Conference on Human Computer Interaction, 2005.

[29] SØRENSEN, S.: The Development of Augmented Reality as a Tool in Architectural and Urban Design, Nordic Journal of Architectural Research, Vol. 19, No. 4, pp. 25-32, 2006.

[30] CIRULIS, A., and BRIGMANIS, K.: 3D Outdoor Augmented Reality for Architecture and Urban Planning, Procedia Computer Science, Vol. 25, pp. 71-79, 2013.

[31] FUKUDA, T., ZHANG, T., and YABUKI, N.: Improvement of Registration Accuracy of a Handheld Augmented Reality System for Urban Landscape Simulation, Frontiers of Architectural Research, Vol. 3, No. 4, pp. 386-397, 2014.

[32] MORI, M., ORLOSKY, J., KIYOKAWA, K., and TAKEMURA, H.: A Transitional AR Furniture Arrangement System with Automatic View Recommendation, Proceedings of the 15th IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct), 2016.

[33] SILTANEN, S.: Diminished Reality for Augmented Reality Interior Design, The Visual Computer, Vol. 33, No. 2, pp. 193-208, 2017.

[34] MORI, S., IKEDA, S., and SAITO, H.: A Survey of Diminished Reality: Techniques for Visually Concealing, Eliminating, and Seeing Through Real Objects, IPSJ Transactions on Computer Vision and Applications, Vol. 9, No. 17, 2017.

[35] GEORGEL, P., SCHROEDER, P., BENHIMANE, S., HINTERSTOISSER, S., APPEL, M., and NAVAB, N.: An Industrial Augmented Reality Solution For Discrepancy Check, Proceedings of the 6th IEEE and ACM International Symposium on Mixed and Augmented Reality, pp. 111-115, 2007.

[36] KAHN, S., WUEST, H., STRICKER, D., and FELLNER, D.: 3D Discrepancy Check via Augmented Reality, Proceedings of the 9th IEEE International Symposium on Mixed and Augmented Reality, pp. 241-242, 2010.

[37] GOLPARVAR-FARD, M., SAVARESE, S., and PEÑA-MORA, F.: D4AR - a 4-dimensional Augmented Reality Model for Automating Construction Progress Monitoring Data Collection, Processing and Communication, Journal of Information Technology in Construction, Vol. 14, pp. 129–153, 2009.

[38] PORTER, S., MARNER, M., SMITH, R., ZUCCO, J., and THOMAS, B.: Validating Spatial Augmented Reality for Interactive Rapid Prototyping, Proceedings of the 9th IEEE International Symposium on Mixed and Augmented Reality, pp. 265-266, 2010.

[39] JOSE, R., LEE, G., and BILLINGHURST, M.: A Comparative Study of Simulated Augmented Reality Displays for Vehicle Navigation, Proceedings of the 28th Australian Conference on Computer-Human Interaction, pp. 40-48, 2016.

[40] PFANNMÜLLER, L., KRAMER, M., SENNER, B., and BENGLER, K.: A Comparison of Display Concepts for a Navigation System in an Automotive Contact Analog Head-up Display, Proceedings of the 6th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, pp. 2722-2729, 2015.

[41] AKAHO, K., NAKAGAWA, T., YAMAGUCHI, Y., KAWAI, K., KATO, H., and NISHIDA, S.: A Study and Evaluation on Route Guidance of a Car Navigation System Based on Augmented Reality, Proceedings of International Conference on Human-Computer Interaction, pp. 357-366, 2011.

[42] TACHI, S., INAMI, M., and UEMA, Y.: The Transparent Cockpit, IEEE Spectrum, Vol. 51, No. 11, pp. 52-56, 2014.

[43] AITEANU, D., HILLERS, B., and GRÄSER, A.: A Step Forward in Manual Welding: Demonstration of Augmented Reality Helmet, Proceedings of the 2nd IEEE and ACM International Symposium on Mixed and Augmented Reality, p. 309, 2003.

[44] HILLERS, B., AITEANU, D., TSCHIRNER, P., PARK, M., GRÄSER, A., BALAZS, B., and SCHMIDT, L.: TEREBES: Welding Helmet with AR Capabilities, Proceedings of Virtual and Augmented Reality Status Conference, 2004

[45] OSTENDORP, M., LENK, J., and LÜDTKE, A.: Smart Glasses to Support Maritime Pilots in Harbor Maneuvers, Procedia Manufacturing, Vol. 3, pp. 2840-2847, 2015.

[46] SHIMODA, H., ISHII, H., YAMAZAKI, Y., and YOSHIKAWA, H.: A Support System for Water System Isolation Task in NPP by Using Augmented Reality and RFID, Proceedings of the 6th International Conference on Nuclear Thermal Hydraulics, Operations and Safety, N6P205, 2004.

[47] DROEIVOLDSMO, A.: Using Wearable Equipment for an Augmented Presentation of Radiation, Proceedings of the EPRI Wireless Technology Conference, 2002.

[48] KLINKER, G., CREIGHTON, O., DUTOIT, A., KOBYLINSKI, R., VILSMEIER, C., and BRÜGGE, B.: Augmented maintenance of powerplants: A Prototyping Case Study of a Mobile AR System, Proceedings of IEEE and ACM International Symposium on Augmented Reality, pp. 124-133, 2001.

[49] PRISACARIU, V., KÄHLER, O., GOLODETZ, S., SAPIENZA, M., CAVALLARI, T., TORR, P., and MURRAY, D.: InfiniTAM v3: A Framework for

Large-Scale 3D Reconstruction with Loop Closure, arXiv: Computer Vision and Pattern Recognition, arXiv: 1708.00783, 2017.

[50] YAN, W., AOYAMA, S., ISHII, H., SHIMODA, H., SANG, T., INGE, S., LYGREN, T., TERJE, J., and IZUMI, M.: Development and Evaluation of a Temporary Placement and Conveyance Operation Simulation System Using Augmented Reality, Nuclear Engineering and Technology, Vol. 44, No. 5, pp. 507-522, 2012.

[51] Inscape AR: http://www.inscape3d.com/en/markets/remote-assistance, (Accessed September 1, 2017).

[52] Remote AR: https://www.scopear.com/products/remote-ar/, (Accessed September 1, 2017).

[53] ASSIST: http://www.cn2tech.com/assist, (Accessed September 1, 2017).