Augmented reality: fundamentals and nuclear related applications

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Abstract: In recent years, Augmented Reality (AR) has attracted considerable interest from both academia and industry. Virtual Reality enables users to interact only with virtual objects in a virtual environment, but AR enables users to interact with both virtual objects and real objects in the real world. This feature supports application of AR to various fields such as education, driving, entertainment, and navigation. Especially, by application of AR to support workers in nuclear power plants, it is expected that working time and human error can be decreased. However, many problems remain unsolved to apply AR to real fields. In this lecture note, fundamental knowledge of AR is presented first including the overview of elemental technologies to realize AR. Then various AR applications to nuclear fields are described. Finally, future prospects are given.

Keyword: augmented reality; tracking; display devices; maintenance support; decommissioning support

1 Introduction

Augmented Reality (AR) is a technology that makes us feel as if imaginary objects actually exist in front of us by making us simultaneously perceive both stimuli from the real world and stimuli generated artificially[1-5]. In a broad sense, target senses of AR include all human senses, including visual, auditory[6], and tactile[7]. However, most existing AR-based systems enhance a user's visual perception by superimposing computer graphics over the user view.

For example, as presented in Fig. 1, if computer graphics of flowers are drawn properly according to a user's current position and orientation, and if they are superimposed over the user view, the user can feel that

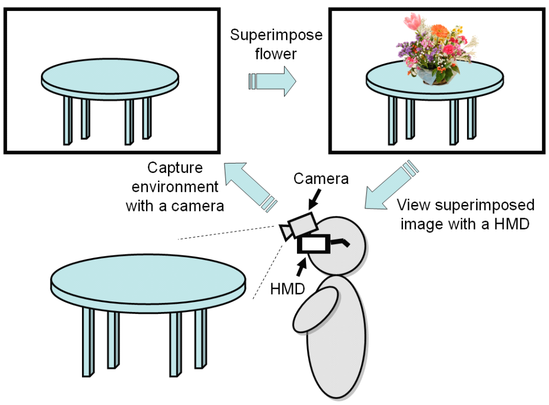

Fig. 1 Example of AR for visual perception.

the flowers are actually exist in front of the user. An important feature of AR is that, as the users change their perspective, the computer graphics are updated properly according to their current position and orientation, and the flowers appear where they are presumed to be. This important feature not only increases the realism of the flowers. It also becomes possible to show the three-dimensional position of the flowers intuitively.

Although Virtual Reality (VR)[8] enables users to interact only with virtual objects in a virtual environment that is simulated completely by computers, AR enables users to interact with both virtual objects and real objects in the real world. Therefore, the application area of VR is limited to operation or acquisition of information, but the application area of AR is much wider: users are presumed to operate not only information but also real objects in the real world[9, 10]. This feature supports application of AR to various fields such as education, training, and maintenance to enhance safety and efficiency in nuclear power plants (NPPs).

In this lecture note, fundamental knowledge of AR is presented first, including the overview of elemental technologies. Subsequently, various AR applications to nuclear fields are described. Finally, future prospects are given.

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2 Features of AR

AR has notable features that distinguish it from legacy interfaces when applied to support workers in NPPs. Concretely, AR offers three specific features as below:

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

Because of these features, AR is expected to realize various applications to support workers in NPPs. AR can increase work efficiency and bring reductions in working time and human error.

2.1 Intuitive indication of position and orientation

It is possible to show an object's three-dimensional position and orientation more intuitively using AR than using legacy interfaces such as paper instruction documents or two-dimensional displays. For example, a worker using a paper-based instruction document (see left-hand side of Fig. 2) must look at the document and apparatus alternately, expending time and energy solely for the necessary eye movement. However, when a worker's view is superimposed with the indication representing the location of the target equipment directly (see right-hand side of Fig. 2), the amount of eye movement can be decreased. That feature can decrease the working time, fatigue, and possibility of committing human error.

2.2 Making invisible information visible

For the example of "making invisible information visible", it becomes possible to make workers feel as if they can view invisible information by visualizing parameters such as kind, pressure, temperature and amount of a pipe's internal flow (see Fig. 3). Through this extension of the worker's perception, it becomes

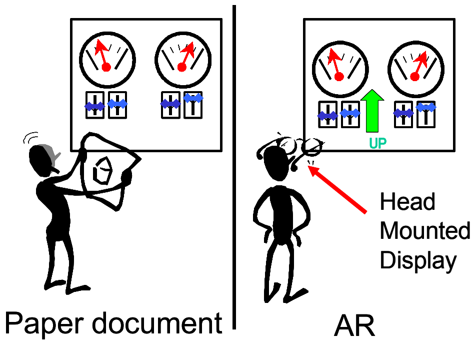

Fig. 2 Comparison between paper-based instruction and AR-based instruction.

Fig. 3 Visualizing inside flow of pipes.

easy for workers to understand the current situation of plants.

2.3 Easy comparison between real and virtual

By superimposing virtual objects over real objects, it becomes easy to compare them and find the difference. For instance, a computer aided design (CAD) model representing pipes existing in a database, if superimposed over real pipes in the real world, simplifies a viewer's comparison of the pipes in the database and the pipes in the real world (Fig. 4). If a difference exists between the database and the real world (*e.g.* if a new pipe was added but the database was not updated), then the viewer can easily identify how the database should be updated.

3 Elemental technologies of AR

AR effect is realized by the following steps:

Step1. Measure the position and orientation of users,

Step2. Generate computer graphics according to a user's position and orientation so that virtual objects are aligned properly with the real world, and

Step3. Display generated computer graphics to users.

The technology for Step 1 is called "tracking". This technology is necessary to realize VR based-systems. Various methods are proposed. Some are

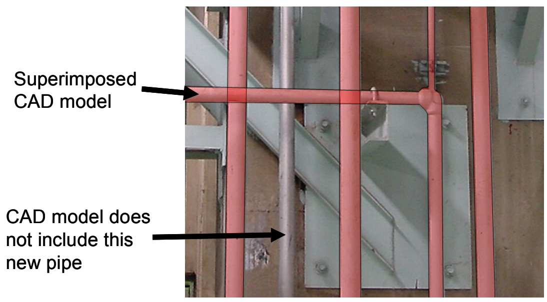

Fig. 4 Easy comparison between real and virtual.

commercially available. However, the performance necessary for AR is higher than that for VR because humans can easily notice misalignment of virtual objects to real objects. Various studies have been conducted to increase the performance of this technology.

The technology used for Step 2 is called “registration”. There are two types of registration error: static error and dynamic error. Static error is a spatial error that represents the difference of three-dimensional position and orientation between virtual objects and real objects. The dynamic error is a temporal error that represents the time difference between virtual objects and real objects. For example, if the user moves quickly and generation of computer graphics cannot follow the speed of the movement, the position of virtual objects cannot be aligned properly to real objects. In some applications such as those for amusement, decreasing the dynamic error is a crucial challenge. In other applications such as maintenance support, decreasing the static error is more important than decreasing the dynamic error. In fact, large static error might lead to misunderstanding of instructions and cause human error. In some cases, still images are sufficient to assist workers[11]. For example, if necessary work is only to understand the current flow of a certain pipe, augmenting the value on a still picture is sufficient for the purpose.

A technology for Step 3 is called “display”. In the case of VR, a crucial challenge is how to display three-dimensional computer graphics of a virtual world to users such that it resembles the real world. However, for AR, a crucial challenge is how to make users view both real world and virtual world stimuli simultaneously such that neither disturbs the user’s activity in the real world.

To conduct the above three steps properly with sufficient accuracy, some characteristic parameters of environments, instruments, and users must be obtained. For example, to generate stereo computer graphics properly, the distance between both eyes must be known. However, the distance differs among people. A technology to obtain the characteristic parameters is called “calibration”.

The following subsections describe state-of-the art tracking technology and display technology, which are crucial technologies to develop AR-based systems.

3.1 Tracking technology

Many tracking methods have been developed and applied to various AR applications. Those methods use satellites[12], wireless LAN[13], inertial sensors[14], magnetic sensors[15], ultrasonic sensors[16], vision sensors[17-24], and so on: each entails advantages and disadvantages, as presented in Table 1.

3.1.1 Satellite position tracking

Satellite position tracking is a global navigation system that estimates the position of a receiver by estimating the distances from multiple satellites. Several satellite systems are in service or in development, including GPS, GLONASS, GALILEO, and COMPASS[25]. At least four satellites must be used to calculate a three-dimensional position of the receiver. Distances from respective satellite are estimated based on the transmission times of signals from satellites. Satellite position tracking cannot be used when the user is inside buildings.

3.1.2 Wireless LAN positioning

Wireless LAN Positioning is a technique that uses a wireless LAN signal’s fingerprint and strength to estimate a receiver’s position. Originally, the wireless LAN was not designed for positioning purposes, but it is possible to estimate a receiver’s position when the position of access points and their signal’s strength are known. An important feature of wireless LAN positioning is that it can reuse infrastructure for wireless networking. It is not necessary to install additional equipment if sufficient access points are already installed. This advantage is particularly useful because installing new equipment into NPPs is not desirable. Nevertheless, the accuracy of wireless LAN positioning is insufficient for realizing AR applications for complicated work in NPPs.

3.1.3 Inertial sensors

Inertial sensors of two kinds are applicable for tracking: acceleration sensors and gyro sensors. Each is extremely convenient because no advance installation of any device in the environment is necessary. However, drift error cannot be avoided.

Table 1 Tracking methods and their advantage and disadvantage

Tracking Method	Advantage	Disadvantage
Satellite Position Tracking	• Stable when enough satellites are available. • Available in a broad area. • Absolute position is obtainable.	• Unavailable inside buildings.
Wireless LAN	• Available inside buildings. • Stable when enough stations are available. • No installation is necessary when enough Wireless LAN stations are already installed. • Absolute position is obtainable.	• Accuracy is low. • Only position is obtainable.
Inertial Sensor	• No installation is necessary into environment. • Computational load is very low.	• Accuracy decreases over time because of accumulation of drift error. • Other method need to be used together to obtain absolute position or orientation.
Magnetic Sensor	• Both position and orientation is obtainable with one sensor. • Stable and accurate in well-controlled environment.	• Magnetic source need to be installed in an environment. • Accuracy decreases when a large metal is in the field. • Many magnetic transmitters must be installed to cover a broad area.
Ultrasonic Sensor	• Accurate and stable in well-controlled environment.	• Ultrasonic source need to be installed in an environment. • Accuracy decreases in complicated environment. • Relatively expensive.
Vision Sensor (Marker-based)	• Less expensive • High scalability • Very accurate and stable when enough markers are visible.	• Markers must be pasted and its position and orientation must be measured in advance. • Available only when markers are visible. • Large number of markers must be pasted when a broad area needs to be covered. • Large markers must be pasted when distance between the markers and vision sensor is large.
Vision Sensor (Natural Feature-based)	• No installation is necessary into environment. • Less expensive for executing tracking • High scalability. • Accurate and stable when enough features are visible. • Trackable area can be extended online (SLAM).	• Computational load is high. • Accuracy and stability depends on environment. • Unstable in a dynamic environment where features are not static.

Accuracy will decrease over time because of error accumulation. Moreover, with inertial sensors, only relative values are obtainable against its initial position and orientation. For that reason, some other method must be applied to obtain the initial position and orientation of inertial sensors.

3.1.4 Magnetic sensors

Tracking methods employing magnetic sensors and transmitters are accurate and stable in a well-controlled environment. With one sensor, both the position and orientation are obtainable. Magnetic sensors are nevertheless easily influenced by metal obstacles. Magnetic transmitters must be placed in the environment in advance. Because the range covered by one magnetic transmitter is short, many magnetic transmitters must be placed to cover a broad area. These requirements hinder its use in NPPs.

3.1.5 Ultrasonic sensors

Although tracking methods using ultrasonic sensors are accurate and stable, ultrasonic sensors and sources must be placed in the environment in advance. Using multiple sensors, both position and orientation are obtainable. The range covered by a single ultrasonic sensor is not large. Therefore numerous ultrasonic sensors must be placed to cover a wide area. Ultrasonic sensors are expensive. Therefore, it is not cost effective to use this method in a large environment. Moreover, the accuracy cannot be maintained in a complicated environment because of specular reflections and multi-pass echoes which is caused by multiple reflections of ultrasonic on different surfaces.

3.1.6 Vision sensors

Tracking methods using vision sensors use cameras as sensors. Cameras capture images; then “specific features” on the images are detected using image processing techniques. The feature is a part of the captured image that is distinguishable from other parts of the image. The useful features for the tracking are corners[26], edges[27], and planes[28]. The relative position and orientation between features and cameras are calculated using geometric calculation. This method can be used inside buildings. It is not affected by the existence of metallic objects and no drift will occur over a long period.

Tracking methods using vision sensors are classified into two categories based on the difference of feature types: natural feature-based methods and marker-based methods. Natural feature-based methods use features that originally exist in the environment. Marker-based methods use features on specially designed markers which are pasted in the environment or tracking targets. The markers usually include primitive shapes such as points, squares[17] and circles[18], which are easily recognized using image-processing techniques. In most cases, point features which are small image patches on the primitives are used as features. To decide the position and orientation of a camera, two-dimensional position of the feature points on the captured image and three-dimensional position in the environment of the corresponding feature points are used to solve Perspective n-Point problem[29]. The three dimensional position of the feature points must be measured in advance. To obtain unique solution of the position and orientation of a camera, at least four point features must be recognized on the camera image simultaneously.

Natural feature-based tracking presents the advantage that no installation of any device in the environment is necessary. However, natural feature-based tracking is accurate and stable only when the environment does not change much. When the environment does change to a sufficient degree, the position of the features also changes, which makes natural feature-based tracking unstable.

The tracking method using vision sensors is also divisible into two categories based on where the cameras are located: inside-out tracking and outside-in tracking, as depicted in Fig. 5. For the former, cameras are attached to users and capture the users' surrounding view. For the latter, cameras are fixed in the environment to capture users.

To use the outside-in tracking in NPPs, many cameras must be placed in the environment because one camera can capture only a limited area. But NPPs are extremely large. Therefore, this setup is very expensive and requires much work to prepare and maintain. In most cases, inside-out tracking is used. Conventional web cameras are useful as sensors and images captured for the tracking can also be used to generate superimposed images for displaying to the users, which means that additional cameras are not necessary.

3.2 Tracking methods that are applicable in NPPs

3.2.1 Problems of existing tracking methods

As a matter of fact, presently almost all existing tracking methods described above are not useful in NPPs. Satellite position tracking cannot be used inside buildings. The accuracy of wireless LAN positioning is insufficient for supporting complicated work. Inertial sensors' error increases over time. Magnetic sensors and ultrasonic sensors are not useful in complicated environments with many metal instruments. Only vision sensors are useful in NPPs and provide sufficient accuracy.

Vision sensors are stable and accurate only when sufficient features are obtainable from captured

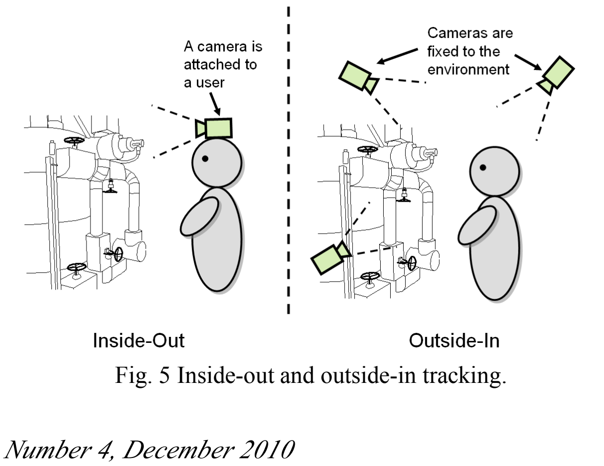

Fig. 5 Inside-out and outside-in tracking.

images. The natural feature-based method is accurate and stable only when the environment does not change much over time. However, the environment in NPPs changes greatly over time. Therefore, marker-based tracking is used in many AR applications for NPPs.

The use of many kinds of markers for tracking has been proposed in the literature[17-22]. The most popular design is square marker, as presented in Fig. 6[17]. The square marker presents the advantage that sufficient feature points are obtainable from one marker (four corners are treated as feature points). This advantage makes the use of the tracking easy. However, a square marker is useful only for the short distance within about 3 meters between cameras and markers. For longer distances, the marker must be so large as to be unacceptable when pasted in NPPs. Marker-based tracking also requires much work for the preparation. Many markers must be pasted in the environment. Moreover, their position and orientation must be measured in advance. Several studies have been conducted to reduce the work necessary for the preparation[20, 21][30].

3.2.2 Tracking method using line markers

It is difficult to paste large square markers in NPPs, but many pipes with thin rectangular surfaces are useful to paste line-shaped markers as depicted in Fig. 7[20]. A line marker basically consists of two types of black elements. Each element corresponds to one bit: the square element and double-sized rectangle element denotes "0" and "1" respectively. These bits are used to distinguish the markers. Since the line marker shape is almost a single line, it is easy to paste on the pipes that are ubiquitous in the plants. It becomes possible to

Fig. 6 Example of square marker.

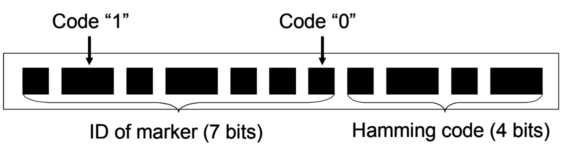

Fig. 7 Example of line marker.

recognize the marker even from an extremely long distance.

3.2.3 Tracking method using multi-range markers

The square markers and the line markers are useful only for short and long distances, respectively. Therefore, when AR is used in NPPs where workers move throughout a large area, both square markers and line markers must be pasted everywhere in the plant. However, it is difficult to paste many markers in NPPs because of their complex and narrow interior.

Multi-range marker is proposed to decrease the number of markers that must be pasted in the plant. The multi-range marker is illustrated in Fig. 8[21]. The marker consists of one large circle located at the center and four small circles at the four corners. The centers of the circles are used as features. The large circle comprises one black outer circle, one white center circle, and one middle circle that consists of black or white fans, which represent a binary code: the white fan denotes "1" and the black fan denotes "0" respectively. These bits are also used to distinguish the markers.

When the distance between a camera and markers is long, the camera captures plural markers, but they are small on the resulting image. When a marker is small on the image, recognizing the large circle is easy, but recognizing the small circles is difficult. Therefore, only one feature is obtainable from one marker, but a sufficient number of features for tracking are obtainable from plural markers. In contrast, when the distance between a camera and markers is short, few markers can be captured, but they appear as large on the image. When a marker on the image is large, it is easy to recognize small circles. Therefore, a single marker provides sufficient features for tracking.

Using the multi-range markers, it becomes possible to

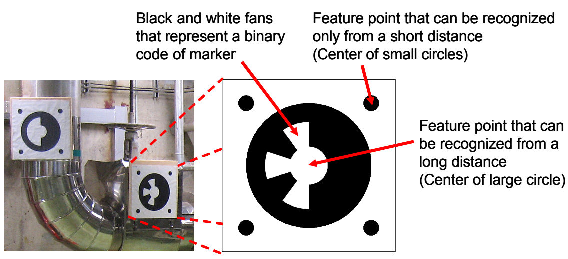

Fig. 8 Example of multi-range marker.

enlarge the area usable for tracking compared to that for line and square markers with a limited space for pasting markers.

3.2.4 Automatic marker registration system

To use marker-based tracking methods, it is necessary to measure the position and orientation of markers in advance. However, it is difficult and time-consuming to measure them manually.

To solve this problem, an Automatic Marker Registration System that can measure the position and orientation of markers automatically was developed as presented in Fig. 9[31]. The system includes a camera with focal length that can be changed, a laser range finder that can measure distance accurately, a motion base that can rotate the camera and the laser range finder, and a computer to control the equipment.

This system recognizes all the markers pasted in the environment and estimates their direction and distance by rotating the camera and capturing images of its surrounding environment. The estimated direction and distance are used to change the direction and focal length of the camera to enlarge the recognized marker at the center of camera image. Then the system tries to pinpoint the laser range finder to the features on the markers and measure the accurate direction and distance. By measuring all five features on the marker, it becomes possible to calculate both the position and orientation of the marker in terms of the world coordinates. The world coordinate is defined using 3 markers pasted in the environment, and these markers are also measured with the automatic marker registration system. The system can refer the measurement result to convert the measurement result of the other markers from the local coordinate system to the world coordinate system. Three measured points are sufficient to decide the orientation of the markers.

This system can reduce the preparation work necessary for marker-based tracking, because all that the user has to do is to past markers, assemble the system and start the measurement. This is much easier than the measurement using rulers.

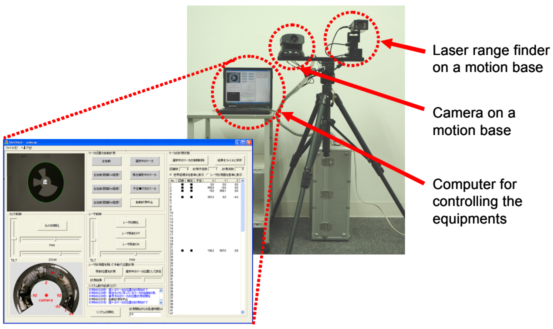

Fig. 9 Automatic marker registration system.

3.3 Display technology

Various display devices are useful for AR. One way to categorize these devices is based on where the computer graphics and real world are combined[31]. According to this categorization, the display devices are classified into retinal display, head-mounted display, handheld display, spatial see-through display and projection display, as shown in Fig. 10. Both the retinal and head-mounted display is attached to user's head. The handheld display is held by user's hand. The spatial display is placed in the space where users conduct activities. The projection display uses objects located in the environment as the projection surface, which means the user does not see the display device itself (in this case, the display device is a projector).

3.3.1 Retinal display

The retinal display draws images directly on the retina of the eyes using a laser. In this case, computer generated images and the real world image are combined on the retina. This display presents many advantages over legacy displays such as Liquid Crystal Display (LCD). The drawn image can be much brighter. Therefore the display is useful in a very bright environment. Furthermore, power consumption is very low. It is possible to realize very high resolution. Moreover, it is possible to make the display very light in weight. It can provide hands-free viewing. Because of these advantages, the retinal display is promising for use in NPPs.

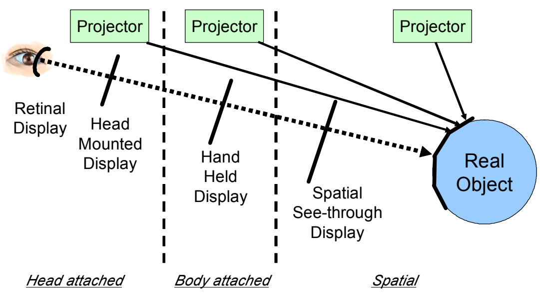

Fig. 10 Display devices used for AR[31].

3.3.2 Head-mounted display

A head-mounted display (HMD) is worn on a user's head and provides images in front of the user's eyes. The computer images and the real world are combined in front of the user's eyes. The HMD is divisible into two categories: optical-see-through HMD and video-see-through HMD. The optical-see-through HMD uses optical combiners located in front of the user's eyes to superimpose virtual objects onto a real view. The combiner is a half-mirror by which the user can look through them directly to view the real world. Users can also see virtual objects reflected on the combiners. The video-see-through HMD uses one or two cameras that provide the user's view of real world. Images from the cameras are combined with images of virtual objects through image processing. The formed combined image is sent to monitors located in front of the user's view in the HMD.

Both types of HMD can provide hands-free viewing. The optical-see-through HMD presents the advantage that there is no time delay, spatial drift, or degradation of real world images. The user's view to the surrounding environment will not be obstructed even if the HMD is broken. However, this HMD also presents the disadvantages that it is difficult to see both real-world and virtual objects simultaneously because the focal distance between them is usually different. The video-see-through HMD has important advantages, because it is easy to align virtual objects to the real world and it provides brighter images compared to the optical-see-through display. However, this HMD also has disadvantages: It entails a time delay and a limited resolution for computer images. It also presents a spatial gap between the displayed images and the user's perspective.

3.3.3 Handheld display

A handheld display is a display used to hold by hands instead of being attached to a head. The computer images and real world are combined on the handheld display. Usually, the device size is small enough for easy holding for a long time. However, that convenient feature necessitates a small screen. When the handheld display is used as a display device for AR, the user can feel that they see the augmented world through the small window. They can change the position and orientation of the window as they want.

The advantage of the handheld display is that users can change the mode of "in use" and "not in use" quickly. Therefore, the users can concentrate on their work when they do not need support by the system. However, it is inconvenient that the users cannot conduct work that requires using both hands when they use the device. Moreover, it is difficult to show detailed information on the small screen.

3.3.4 Spatial see-through display

A spatial see-through display is a display used by being placed in an environment instead of being held by the hands, as shown in Fig. 11. The computer images and real world view are combined on the display devices placed in environment. When using the spatial see-through display, they can feel as if they see the augmented world through a window the size of which is larger than that of the handheld display.

When the spatial see-through display is used for AR, it becomes easy to generate superimposed images more accurately because the area where the display device will move is limited. The advantage of the spatial see-through display is that users need not hold the device and the display size can be larger than handheld one. However, users cannot move around. Therefore, if it is necessary to cover a large area, then many large systems must be installed into an environment. This is not desirable for actual use in NPPs.

3.3.5 Projection Display

The projection display projects computer images onto real physical objects using projectors or laser pointers located in the surrounding environment. The computer images and real world view are combined on the physical objects that are the target for augmentation.

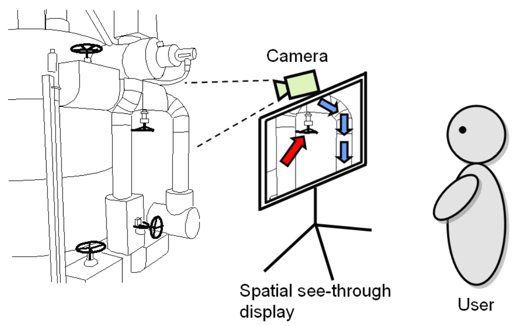

Fig. 11 Spatial see-through display.

Some advantages are that users need not have equipment to use the system, and the system can be shared with other people simultaneously. The superimposition accuracy can be higher than that of other displays because it is not necessary to track the users to project the computer images at the correct position. Some disadvantages are that the superimposed images might be difficult to see in a bright environment and the area in which the superimposed images can be projected is small. Therefore, many projectors must be used to cover a large area.

3.3.6 Display devices that are useful in NPPs

The complexity of NPPs dictates many of the requirements of displays used for AR. It is preferred to use a retinal display or HMD because these displays can provide hands-free viewing and workers can continue to work while using them. However, workers in NPPs must watch their feet while walking because the floors in NPPs are not flat and many objects are placed on the floor. In addition, workers must be careful not to hit their head on protruding obstacles such as pipes and valves. The video-see-through HMD limits the workers' view. It is therefore unacceptable from safety aspect. Retinal display and optical-see-through HMD can solve this problem, but accurate alignment of virtual objects to real world objects strictly necessitates that the displays be attached to the workers. If the display is shifted from its original position, then it must be corrected. Without this correction, the virtual objects will be aligned to the wrong position and might lead to some misunderstanding. Using the current technology, it is difficult to conduct this correction properly. Therefore, a retinal display and optical-see-through HMD are not applicable for use in NPPs. Because of these problems, a handheld display or spatial see-through display is used in the application, as will be described in next section. However, the screen of the handheld device is too small and workers cannot move freely with the spatial see-through display. A new display device must be developed to solve these problems.

4 Applications of AR

By applying AR, it is possible to support workers in NPPs. In this section, some application examples are stated.

4.1 Maintenance support using AR

One noteworthy feature of AR is that it can display the three-dimensional position and orientation intuitively. One application that uses this feature is a support system for a water system isolation task[32].

In NPP's periodic maintenance work, some water systems must be isolated by valve operation to disassemble and check plant equipment. It is, however, difficult to find specified valves because a huge number of valves are present in NPPs.

Figure 12 presents a support system for water system isolation task. The system comprises a portable computer, camera, display device and RFID reader. Markers are pasted in environment; their position and orientation are measured in advance. When the camera captures the environment, the camera position and orientation are calculated in real time and the system checks whether or not the target valve is in the worker's view. If the target valve is in the worker's view, the system generates superimposed images, as presented in the left-hand of Fig. 13 to show the position of the target valve. If the target valve is not in the worker's view, then the system generates superimposed images as presented in the right-hand of Fig. 13 to show the direction where the target valve

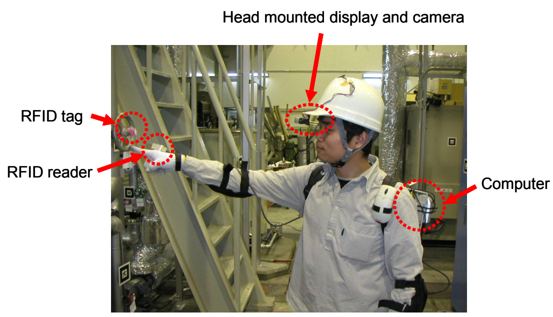

Fig. 12 Support system for water system isolation task.

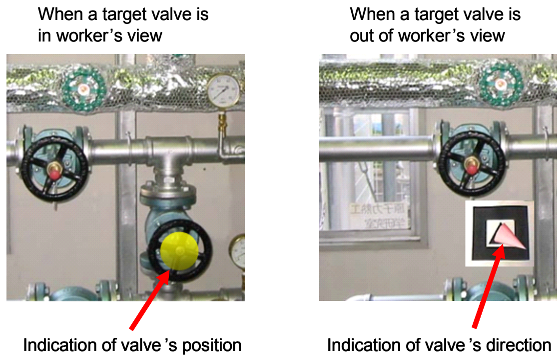

Fig. 13 Indication of target valve using AR.

exists. By viewing these superimposed images, the worker can find the target valve easily. This system also provides a function by which the worker can confirm whether or not the valve he/she found is a correct one, by scanning the RFID tags pasted on each valve with RFID reader attached to the worker's hand.

4.2 Radiation visualization using AR

Another AR feature is that it can make invisible information visible. This feature is useful to realize dose-rate visualization[33]. Field workers must avoid approaching high radiation areas to minimize total radiation exposure. However, that is not easy to achieve because radiation is invisible. Using AR, it becomes possible to visualize the radiation distribution to provide greater awareness, as presented in Fig. 14. With this visualized view, workers can choose a route to the destination to avoid the hot areas.

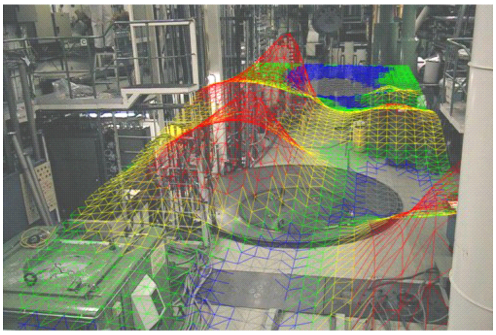

Fig. 14 Radiation visualization using AR [33].

4.3 Decommissioning support using AR

The feature by which AR can make it easy to compare real objects and virtual objects is useful to support recording the progression of dismantling work.

Even if the service period of NPPs terminates, some parts of NPPs are radioactive. For that reason, workers must follow detailed plans when they dismantle the NPPs. Moreover, the workers must record their work progress because the dismantled parts must be under control before their clearance level inspection.

Figure 15 portrays a dismantling support system using AR[34]. This system provides two kinds of support functions: reference support of cutting parts and recording support of work progress.

When supporting a reference of cutting parts, a worker uses a small tablet PC with a camera on its reverse side,

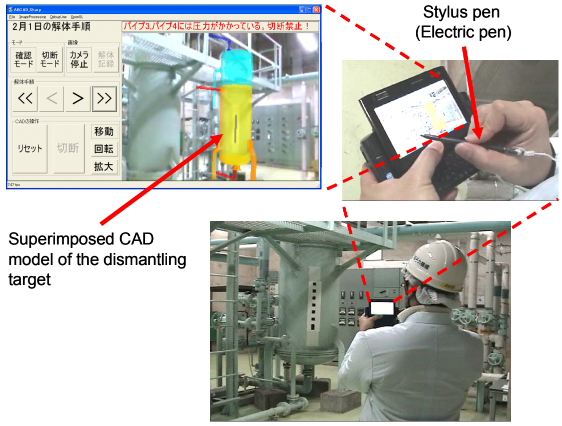

Fig. 15 Dismantling support system using AR.

as depicted in Fig. 16. When the camera captures a dismantling target, the image will appear on the PC's screen with a three-dimensional model of the dismantling target being superimposed. The superimposed model is drawn with different colors according to its meaning: already dismantled, should be cut and should not be cut. The workers can refer to the colored model to find the cutting parts and restraint parts intuitively.

When supporting a record of work progress, a worker uses the same PC as the case of supporting reference of cutting parts, as presented in Fig. 17. However, this

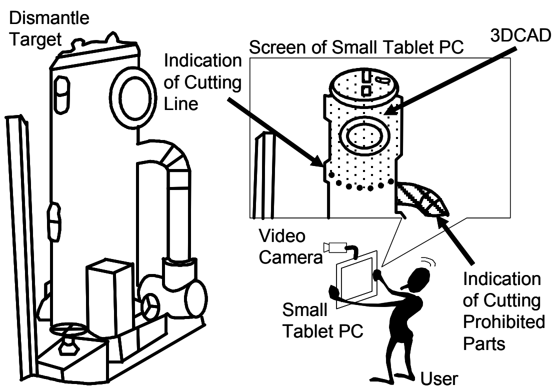

Fig. 16 Reference support of cutting parts.

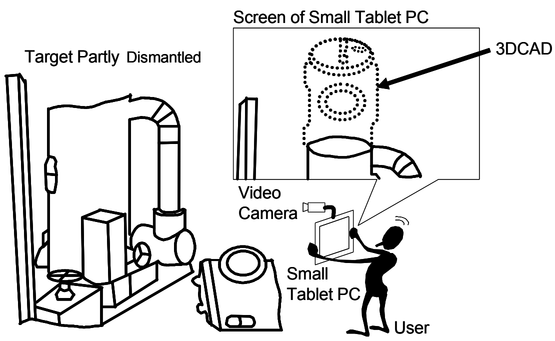

Fig. 17 Recording support of work progress.

time, the worker uses the system after finishing the dismantling work of the day and the superimposed model represents the state before starting the dismantling work of the day instead of the current state of the dismantling target. Of course, some different parts exist between the real dismantling target and the superimposed model. This difference represents the progress of the dismantling work of the day. Therefore, by displaying the difference between virtual and real circumstances, it is possible to record the work progress intuitively.

5 Future prospects

In this lecture note, the great possibility of AR is presented with some example applications to nuclear fields. However, many problems should be solved before pursuing their widespread application.

For example, in actual maintenance work in NPPs, workers spend much time not only for maintaining and dismantling equipment but also for field investigations, planning, material procurement, pre-work meeting, preparation, clean up, and so on. Therefore, even if an AR-based system can support workers only at the moment of maintaining or dismantling equipment, its effect is not large. The workers will not want to use the system unless the necessary work for introducing the system is small. Especially, some applications introduced in this lecture note assume that a three-dimensional model of the target equipment is already available. However, such a model is not available for old plants; it must be made from scratch. Although most of recent plants are designed using a computer aided design system, much work is still necessary to make the existing design data useful for AR application. It is necessary to control the plant design process properly in order to consider the application to AR.

As one future challenge, it is necessary to develop authoring tools that can enable us to prepare contents of AR without much effort or expert knowledge. Moreover, it is necessary to realize a total solution that is effective not only for supporting maintenance or dismantling work itself at the field but also for NPP whole-lifecycle management.

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