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Applicability of AR-based Maintenance and Test Support System in NPPs

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1. Introduction

Augmented Reality (AR) is a new technology that integrates virtual reality with the real world. This integration is in the form of video images digitally augmented with computer-generated graphics [1]. One function of AR is to improve the sense of the reality of virtual objects. That is, the information can be delivered to users in three dimensions (3D) more intuitively than paper manuals or conventional 2D interfaces [2,3]. AR can reduce the cognitive load of workers and increase work efficiency by intuitively providing user-centered information in various environments. In addition, training with AR can, increase the task understanding and reduce its time by realizing the task environment in a virtual environment [4].

Many industries are supporting maintenance work by introducing AR technology to task training [5]. AR technology has a wide range of applications and can be easily implemented in many processes, especially in the maintenance tasks. AR technology provides intuitive additional information during maintenance tasks. These supports can help workers to easily perform complex tasks and reduce their operational errors [5,6].

In NPPs, events that include accidents and breakdowns occur for various reasons. According to the Nuclear Power Plant Operation Performance Information System (OPIS), the events caused by human errors consist about 17.7% of total events in domestic NPPs from 1978 to March 2022. In this database, operator errors during maintenance are one of the proportions of human errors [4,7].

This paper specifically considers the applicability of AR technology during the Overhaul (O/H) period when maintenance tests are performed by NPPs' on-site operators. This paper also explains advantages of AR technology that affect the performance of operator's tasks when applied.

2. Application of Augmented Reality (AR)

This section introduces the cases of AR application in nuclear and other industries.

2.1 Application of Augmented Reality in Other Industries

Recently, AR technology has been applied to various industrial tasks. They apply AR technology for training, responding to hazardous tasks, and improving work efficiency within a limited time. There are two examples as described below.

As a first example, the oil and gas industry applied AR technology to train beginners for maintenance work [8]. According to the literature, workers experienced the feeling of 'learning while doing' through the various senses simulated by AR technology. In addition, they can learn how to respond to hazardous task situations by simulating pre-generated scenarios.

Second is the impact of human errors on operations of maintenance in the aviation industry. Maintenance workers in the aviation industry work under high-pressure conditions and must comply with strict time limits and guidelines. They applied AR technology to intuitively and vividly show the relevant maintenance procedures and step-by-step instructions for fieldwork. In addition, they provide summarized information about maintenance in real-time by using AR. The studies suggested that AR can be used to reduce the difficulty of work and increase work efficiency [2].

The major goals of AR technology in general industries is to improve understanding of their tasks and then reduce their operational errors. When training for task performance by applying AR technology, training is conducted in an environment similar to reality. Through this, by increasing the understanding of the task, the ability to perform the task is cultivated and the task is performed efficiently. In addition, it is possible to improve the ability to cope with accidents through simulation training, thereby reducing human error.

2.2 Application of Augmented Reality in Nuclear Industries

In the nuclear industry, workers contribute to improving the safety of the task environment. In addition, it is done through strict guidelines and proper procedures when workers perform their tasks.

The first application of AR technology in NPPs is suggested the maintenance work of NPPs on-site operators. When events occur on-site, they should physically go there. In that situation, AR application can aid to prevent safety accidents that may occur when on-site operators go to the local maintenance task, and it helps to perform their task by intuitively grasping the condition of the device when starting and proceeding [9].

The second is that AR application was suggested to deal with radioactive materials in the nuclear industry. In the literature, AR application provides intuitive information on what kind of material when storing

radioactive materials, which is important information that enhances the safety of researchers [10,11].

The above studies are focused on the development of the worker support system. By applying AR technology as a support system to workers, it is possible to reduce human error by intuitively providing information necessary for work.

3. Applicability of AR-based Maintenance and Test Support System (AMTS) in NPPs

This section introduces a case-study in NPP to suggest applicability of AR-based Maintenance and Test Support System (AMTS). Then, this study shows the procedure for the development of AMTS.

3.1 Applicability of AR for supporting maintenance and test

During the O/H period for the Wolsong Unit 3 of Korea Hydro & Nuclear Power (KHNP), the drain valve of the pressurizer (PZR) was manually opened while cooling and depressurizing the Reactor Coolant System (RCS), and the primary system water leaked. This is an incident that occurred due to a misunderstanding of the valve of the PZR while on-site operators were performing their tasks. Specific causes were analyzed as insufficient management of nameplates for valves and lack of training for on-site operators to check and operate local devices. Through this case, it can be seen that when on-site operators perform a task, the location and information of the local device must be accurately known, and the understanding of the task must be high [7].

The point of the incident mentioned above is that the on-site operators require additional information about on-site components, i.e., location, operation steps, and understanding tasks when recovering the incident. AR technology can support on-site operators of NPPs to provide operation guideline based on procedures during maintenance work. The main advantage of AR technology is that it intuitively provides the necessary information to the operator. Moreover, during vocational training for unskilled persons, real-world field training in the virtual world improves work understanding and actual work efficiency [4].

3.2 Procedure for the development of AMTS

Following requirements in maintenance and test operation, this study suggests the process to develop AMTS. To develop the AMTS, the following tasks have to be performed in turn; 1) task analysis, 2) function analysis, 3) design of support function, and 4) implementation.

1) Task Analysis

The purpose of task analysis is to define the tasks of on-site operators. Task analysis is performed based on maintenance procedures.

Maintenance procedures are mainly performed through communication between the Main Control Room (MCR) and the on-site operators. The classification of task performance roles between the MCR and the local is as follows;

- Check initial condition (MCR-Local)
- Operate the equipment
- Measure and record the equipment (Local)
- Check the test result criteria

Through the above tasks, it analyzes what functions are needed for on-site operators when applying AR technology.

2) Functions Analysis

The purpose of function analysis is to analyze what functions are required for on-site operators by applying AR technology as a support system when performing a task.

Navigation function: NPP is one of the largest facilities, which is built under a large site. Although on-site operators have expert experience, it is impossible to remember the location and manipulation method of all facilities installed in NPPs. Moreover, if they are not located near the equipment to perform the work, they may not be able to meet the time limit depending on the characteristic of the task. For this reason, the navigation function is required to guide the on-site operators to provide the location of equipment.

Procedures function: The paper-based procedures are not portable by hand. Normally, on-site operators use the procedures an uncomfortable environment that may be moist and dusty. Thus, the procedures can easily become wet or torn. In addition, when using paper-based procedures, operators do not allow additional manipulation because their hands are not free. Fig. 1 shows the Head Mounted Display (HMD) AR device, which is suggested as a device called HoloLens-2 that can possibly provide operating procedures without paper. In addition, the operating procedures should be installed inside the device due to the emphasis of maintaining security without connection to the internet.

Fig. 1. AR device HoloLens-2 of Microsoft

Device information function: Accidents can occur due to incorrect nameplate management of target devices performing maintenance work by on-site operators of NPPs. In addition, there is a problem in task performance due to a lack of training on task performance. On-site operators should be able to train on task performance through various senses through a virtual task environment in an AR environment. Also, information on the target equipment for task performance should be intuitively shown to the on-site operator.

Video communication function: Communication function between on-site and MCR operators is required when performing maintenance tasks. The tasks for, maintenance and test take a lot of time to share the task steps and procedures of on-site operators with the MCR. The operators inside the MCR normally communicate with the on-site operator by using page phones that are attached to the facility. In addition, human error which are incorrect task performance of on-site operators threatens the safety of NPPs.

3) Design of Support Functions

The purpose of the design of support functions is to define what is designable among the functions organized by function analysis. The hardware to apply the analyzed AMTS functions is HoloLens-2 from Microsoft. This device allows on-site operators to perform tasks in an AR environment.

AR environment implementation is developed by Unity engine. The AR environment can be implemented using the Mixed Reality Toolkit (MRTK) in the Unity engine. In Unity, it is possible to describe functions to operate in an AR environment through Scripts based on C# language.

In the case of navigation functions, NavMesh, basic Scripts of Unity, can be used to indicate a walking surface to find a route to the location of the local. In addition, in the case of procedures, Python language-based procedures interface can be applied using the Slate module of Unity. Slate is a reactive interface that can be used through a user's gesture. 3D modeling of NPPs equipment to provide maintenance and operation guidance. However, there are many types of devices in NPPs, and 3D modeling of each device has its limitations. The video connection function may be used using an application embedded in HoloLens-2.

4) Implementation

AMTS works as an application on HoloLens-2. When AMTS is enabled, users can use the functions designed as shown in Fig. 2 in maintenance and test procedures. Among the functions of AMTS, video communication with MCR is operated by an application built into HoloLens-2, and the local navigation function operates by guiding the user to the destination in the AR environment. The procedures function can show the procedure being applied and the step in progress when performing the task through the user's gesture. All of these features are presented as an interface in the user's AR environment.

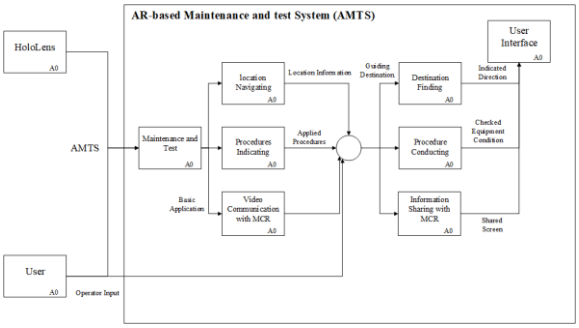

Fig. 2. Architecture of AMTS

4. Conclusions

Accidents and breakdowns occur due to human error in NPPs. Such accidents and breakdowns are important issues that can pose a problem to the safety of NPPs. In this paper, the reason why AR technology should be applied to the maintenance and testing of on-site operators of NPPs and the advantages of applying the technology is explained.

This paper specifically considers the applicability of AR technology during the Overhaul (O/H) period when tests and maintenance are extensively performed by the NPPs' on-site operators. This study also suggested the process to develop AMTS which is AR-based. When AMTS is applied to NPPs, it is expected that human errors that cause accidents at plants can be reduced by supporting the task performance of on-site operators.

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