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A SUPPORT SYSTEM FOR WATER SYSTEM ISOLATION TASK IN NPP BY USING AUGMENTED REALITY AND RFID

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KEY WORDS

Augmented reality, radio frequency identification, maintenance support, water system isolation, usability evaluation

ABSTRACT

Aiming at improvement of task performance and reduction of human error of water system isolation task in NPP periodic maintenance, a support system using state-of-art information technology, Augmented Reality (AR) and Radio Frequency Identification (RFID) has been proposed, and a prototype system has been developed. The system has navigation function of which an indication is superimposed directly on the user's view to help to find the designated valves by AR. It also has valve confirmation function by scanning RFID tag attached on the valve. In case of applying it to practical use, its information presentation device is important because it affects the task performance. In this study, therefore, a suitable information presentation device has been pursued by conducting subject experiments employing psychological experimental technique. The candidates of the devices are one-eye video see-through HMD (SCOPO) and both-eye video see-through HMD (Glasstron) as wearable system configuration, and tablet PC and compact TV as handheld system configuration. In the experiment, task completion time, number of errors, NASA-TLX score as subjects' mental workload and subjective usability questionnaire were measured when using the above devices. As the results, it was found that one-eye video see-though head mounted display, SCOPO was suitable device as wearable system configuration, and compact TV was suitable device as handheld system configuration.

1. INTRODUCTION

In Japan, nuclear power plants (NPPs) should be maintained every thirteen months and their operation should stop for about one month in order to disassemble and check its equipment in this periodic maintenance term. The number of components of NPP is, however, much more than that of same-scale thermal power plant and the maintenance work of NPP is huge because its structure is more complex. In addition, recent deregulation of electric market requires shortening of NPP periodic maintenance time, and lack of expert field workers caused by their retirements becomes a big problem. In order to keep and improve safety and reliability of NPP even in such situation, improvement of maintenance work efficiency and reduction of its cost at the same time is desired.

On the other hand, recent information technologies have been progressed very rapidly. Among them, state-of-art information technologies such as augmented reality (AR) and radio frequency identification (RFID) aim at real world rather than cyberspace. AR is a technology which extends information in real world by superimposing computer-generated virtual objects (text, figure) into user's view (Azuma, 1997). RFID is a technology which automatically identify an object without direct contact by using a RFID scanner and a small RFID tag that is pasted on the object in advance (Sarma, 2001). Recently, these technologies have been developed rapidly for practical use. As mentioned above, it is expected to improve efficiency of maintenance work and reduce human errors by applying these technologies to support the maintenance work of NPP, because these technologies deal with real world. Although AR has a great possibility to apply to various field work support, only some studies can be used in practice (Azuma, 2001).

In this study, therefore, a support system of water system isolation task, which is one of the most important and troublesome tasks in the periodic maintenance of NPP, has been developed by employing AR and RFID. Especially, the authors have paid attention to the information presentation devices of the support system and have developed prototype systems employing typical information presentation devices. And the prototype systems have been evaluated from the viewpoints of task performance, mental workload of the user and their usability by conducting subject experiments and have pursued the suitable information presentation device for the support system.

In the present water system isolation task, field workers seek the designated valves among huge number of valves in a NPP and operate them according to a paper-based instruction sheet. There are, however, still some problems remaining such as time-consuming for seeking the designated valves, possibility of errors when identifying the valve and order of the operations. If AR is applied to the support system to navigate the field worker to the designated valves and to indicate the valve operation, and RFID is applied to confirm the designated valve, most of the above problems are expected to come to a solution.

In this paper, section 2 and 3 will review water system isolation task in NPP, and applied information technologies for the support system. In section 4, the design and development of the support system will be described. The details of experimental methods and results for evaluation of information presentation devices will be described in section 5, and section6 will discuss the results. And the section 7 concludes the study by summarizing the experiment and further works.

2. WATER SYSTEM ISOLATION TASK

Standard step of maintenance work of NPP equipment consists of "system isolation (both electric system and water system)", "data acquisition before disassembling", "disassembling", "cleaning up", "unit examination", "exchange of parts", "assembling", "confirmation of unit operation", "connection with system" and "function examination". During the periodic maintenance, the cooling system should be kept working in order to remove decay heat of the core even if the reactor stops. When maintaining plant equipment, therefore, the equipment should be isolated from the system with the cooling system working.

At present, system isolation task is supported by "system isolation task support system" which is realized as a software mounted on a workstation. The support system prints out paper-based instruction that indicates the valves to be operated. The instruction included IDs of the valves to be operated, their statuses before operation, operations and the results. The field workers conduct the following steps with referring the instruction paper as shown in Figure 1.

(1) walk to the valve location,
(2) look for the valve to be operated with the valve ID,
(3) confirm that the current valve status is the same as that on the instruction paper, and
(4) operate the valve according to the instruction paper.

After conducting all of the operations, they returned to the workstation and input the results in the workstation.

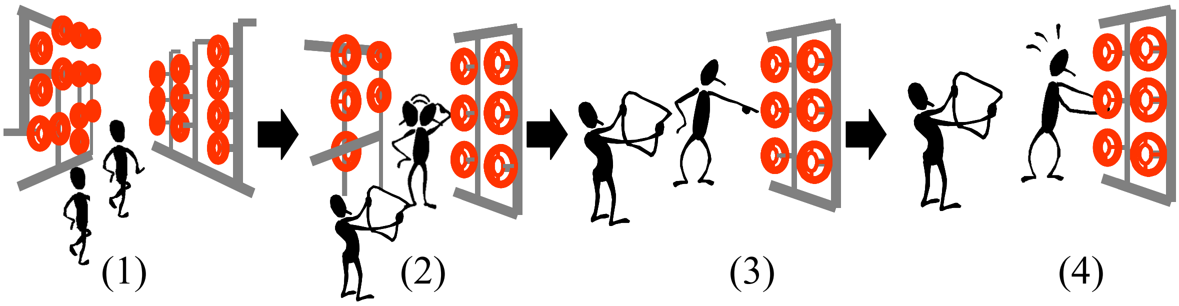


Figure 1. Procedure of water system isolation task.

The above tasks are time-consuming and may cause a mistake because of the following reasons;

(1) Thousands of valves should be operated correctly for the maintenance for hundreds of plant equipment during the periodic maintenance.
(2) Each valve has its original ID, which consists of several alphabets and digits. The field workers should seek the designated valve only with the clue of this ID according to their experience.
(3) There are lots of similar valves in NPP and some of them are congested in one place.
(4) NPP is extensive and the field workers don't have its map that indicates the valve locations.

3. AUGMENTED REALITY AND RFID

3.1 Augmented Reality(AR)

As one of the solution for the above problems of the water system isolation task, AR can be applied. Azuma (Azuma, 2001) defines an AR system as one that "supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world". Wearing a HMD, for example, the user of an AR system can see the real world around him, but with additional virtual objects appropriately aligned (or "registered", in AR terminology) with real objects. As the user moves around in the real environment the virtual objects maintain correct alignment with the physical environment resulting in a seamless combination of real and virtual objects. AR can thus enhance the user's perception of the real world. By using this feature, virtual navigational object to the designated valve can be superimposed upon the worker's environmental view to easily find the valve.

3.2 RFID

Radio Frequency Identification (RFID) is a technology that enables the electronic labeling and wireless identification of objects using radio frequency communications (Finkenzeller, 2001). From a functional point of view, an RFID system consists of three components:

(1) RFID tags into which identification data can be embedded. These are devices that identify the item to which they are attached. RFID tags are also called transponders or more generally contactless data carriers.
(2) RFID scanners (RFID readers) that communicate wirelessly to the tags.
(3) Software application that reads/writes data to/from tags through the reader.

One of the important features of RFID is that RFID tags can work with electricity wirelessly provided by RFID scanners. This means that RFID tags contain no battery in them, so that they need no maintenance. And another feature is that RFID tag can keep more than 100 bytes information in it and they are rewritable with RFID scanner.

4. DESIGN AND DEVELOPMENT OF PROTOTYPE SYSTEM

4.1 Design of Support System

Considering the problems of water system isolation task and the features of AR and RFID, the authors have designed the functions of the support system as follows:

(1) Valve indication function,
The location of the designated valve is indicated by superimposing a virtual object upon the worker's view by AR, when it is within his/her view.

(2) Navigation function,
The direction of the designated valve is displayed onto the worker's view by AR, when it is out of his/her view.

(3) Valve confirmation function,
The found valve is confirmed by RFID scanner equipped with the support system and the RFID tag attached on the valve. The valve ID was registered in the RFID tag and it was attached on the valves in advance.

(4) Management function of task progress.
A sequence of valve operations is managed by the support system in order to keep the correct operation order.

Figure 2 shows the concept of the above function (1), (2) and (3).

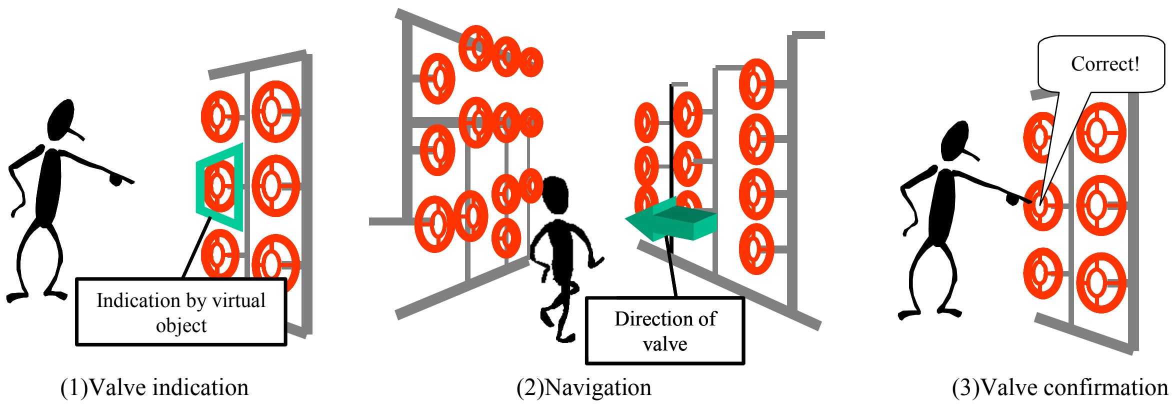


Figure 2. Functions of support system.

In order to realize the above functions, the system structure was designed as shown in Figure 3.

In this study, ARToolKit (Kato 1999) is employed in order to realize AR effect. ARToolKit is a C language library that let developers easily develop Augmented Reality applications. One of the most difficult parts of developing an AR application is precisely calculating the user's viewpoint in real time so that the virtual objects are exactly aligned with real world objects. ARToolKit uses computer vision techniques to calculate the real camera position and orientation relative to AR markers shown in Figure 4. When pasting the AR marker in the real world, ARToolKit can easily calculates relative position and orientation of the video camera to the real world.

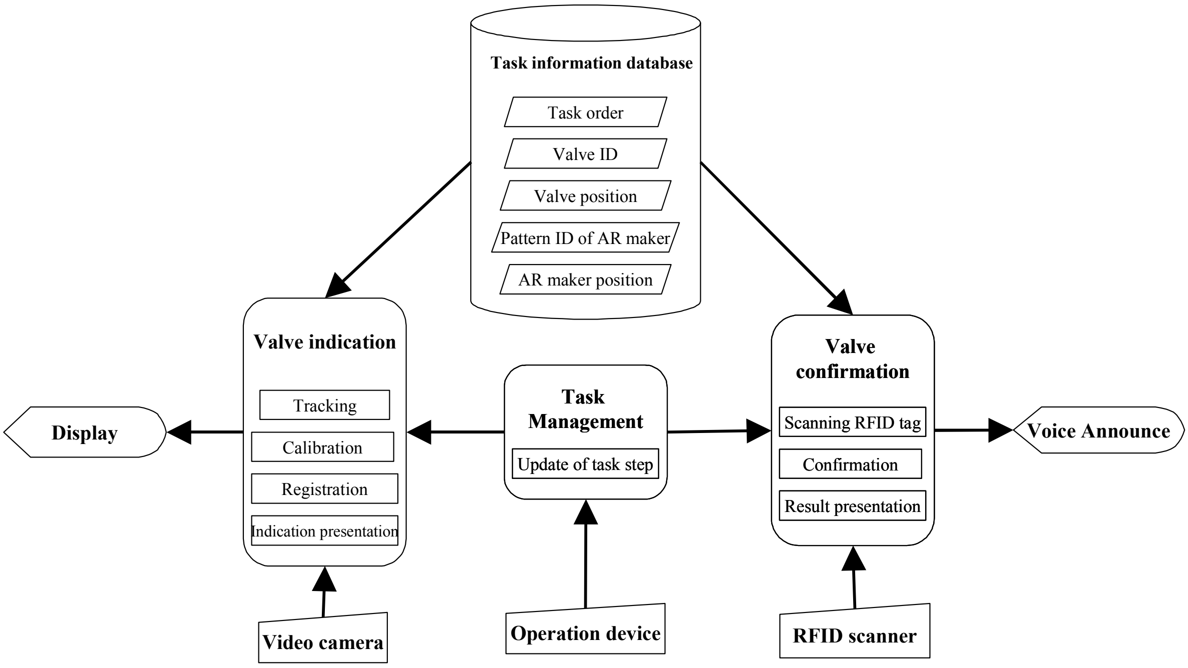


Figure 3. Structure of support system.

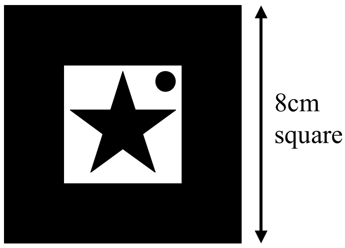


Figure 4. An example of AR marker for ARToolKit.

4.2 Development of Prototype System

According to the above system design, a prototype system has been developed. Figure 5 shows the hardware structure, and Table 1 shows their details.

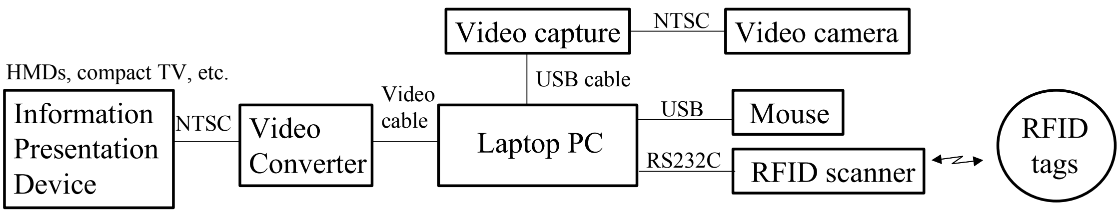


Figure 5. Hardware structure of prototype system.

The software has been developed along with Figure 3 with Microsoft Visual C++ Version 6.0 on Windows 2000.

Table 1. Details of hardware components

Component	Maker	Type
Laptop PC	IBM	Thinkpad X31
Video camera	Watec	WAT-230A
Video capture	IO-Data,	USB-CAP2
Video converter	Digital Arts	DSC06d-HR
Mouse	Microsoft	IntelliMouse
RFID scanner	Omron	V700-HMD11
RFID tag	Omron	V700-D13P21

4.3 Interface System Configuration

Considering the situation of the water system isolation task, the requirements of the system interface are (i)less restriction of worker's movement and (ii)less physical workload of the worker. The visual display used for this system is important because it greatly affects system configuration. The visual displays used in AR systems are classified into three categories, HMDs (sometimes called head-worn displays), handheld displays and projection displays.

The most popular of these displays is the HMD, which is worn on user's head and provides images in front of the user's eyes. There are two main types of HMD: optical see-through displays and video see-through. Optical see-through displays use semi-transparent mirrors to provide a computer generated overlay image over the directly seen background while video see-through displays use video capture from a head-mounted video camera to provide a real background image on which the computer-generated overlay is superimposed. Both display types are usually based on LCD technology because it is small, lightweight and has low power consumption.

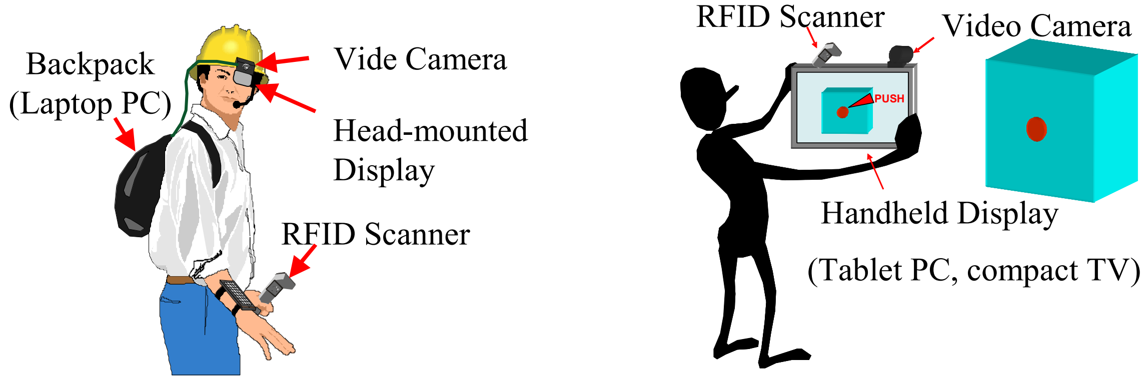
Handheld displays are occasionally used in AR systems. For example, Rekimoto has developed a virtual magnifying glass system, which uses a handheld display (Rekimoto, 1997). In the system, a video see-through approach is applied to overlay the augmentation over the real background view. In addition to virtual magnifying glasses, handheld displays are often used as a kind of window to look into the augmented environment.

Projection displays projects virtual information directly onto physical objects. This type of display typically uses a video projector or a laser pointer (Mann, 2000) as a virtual information projection tool. The merit of the projection display is that the user does not normally (in some systems head-mounted projectors are used) need to wear any display equipment. Also, high accuracy of overlay can be easily realized. The projection displays, however, have a fatal disadvantage for the support system of water system isolation task. They are too heavy to be carried, so that they should be installed in all of the environments.

The system configuration, therefore, is supposed to be (a)wearable configuration as shown in Figure 6(a), or (b)handheld configuration as shown in Figure 6(b).

(a)Wearable configuration employs a head-mounted display (HMD) as its visual information presentation device, while (b)handheld configuration employs a handheld display. The typical information presentation devices for (a)wearable configuration are one-eye optical see-through HMD, video see-through one-eye HMD, and both-eye video see-through HMD. On the other hand, the typical devices for (b)handheld configuration are tablet PC and compact TV.

The visual information presentation device is important because it prescribes the system configuration and it also affects the task performance when using the support system. In this study, therefore, the candidates of the visual information presentation devices have been compared by subject experiment.



(a)Wearable configuration (b)Handheld configuration

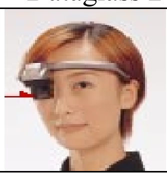
Figure 6. Two types of system configuration.

5. SUBJECT EXPERIMENT

5.1 Purpose of Experiment

As mentioned above, the purpose of the experiment is to compare and evaluate the candidates of the visual information presentation devices of the system. Since the evaluation method should be quantitative, the experiment has been conducted along with psychological experimental method. The candidates of the visual information presentation device are shown in Table 2. They are typical HMDs and handheld displays.

Table 2. Candidates of visual information presentation devices

Device	Dataglass 2	SCOPO	Glasstron	Tablet PC	Compact TV
Appearance					
Type	Wearable	Wearable	Wearable	Handheld	Handheld
Model	Dataglass2, Shimadzu Corp.	SCOPO, Mitsubishi Electric Corp.	Glasstron, Sony Corp.	Travel Mate C100 TMC102I, Acer	SY-4100, Casio Corp.
Features	One-eye optical see-through	One-eye video see-through	Both-eye video see-through	10.4 inch display, 1.4 kg weight	4 inch display, 0.58 kg weight

When wearing Dataglass2, the user can see virtual objects optically through on his/her right eye view, and the size of the displayed area is 13 inches in 60 cm far from his/her eyes. When wearing SCOPO, the user can see 14-inch display 1 meter on far from his/her eyes on the right bottom of his/her view. On the display, the virtual object is superimposed electrically upon the outside view captured by video camera attached on the user's head, so that he/she have to switch his/her view direction to the display when referring the virtual objects. When wearing Glasstron, the user can see

42-inch display far from his/her eyes. The virtual object is also superimposed upon the outside view as well as SCOPO. When using tablet PC and compact TV, the virtual object is superimposed upon the outside view captured by the video camera attached on the back of the devices.

5.2 Experimental Method

The requirements of the experiment are as follows;

(1) Experimental environment should be as similar to real plant environment as possible.
(2) Task given to subjects should be also as similar to real task as possible.
(3) Cognitive biases should be cancelled such as order effect, learning effect and difficulty difference of given tasks.

Considering these requirements, the experimental method was designed. The concrete method will be described in the following subsections.

5.2.1 Experimental Environment

The experimental environment is a micro gas turbine plant (MGT) in Kobe University, Japan, which is the substitute of a real NPP. The MGT has 50 valves in 7.8m x 9.0m area. In the area, ID tags as 4 cm square piece of papers and RFID tags were attached on all of the valves with their registered identification, and 62 AR markers were pasted in advance in order to realize AR effect. Figure 7 shows the top view of the experimental environment, and Figure 8 shows an example of RFID and AR marker.

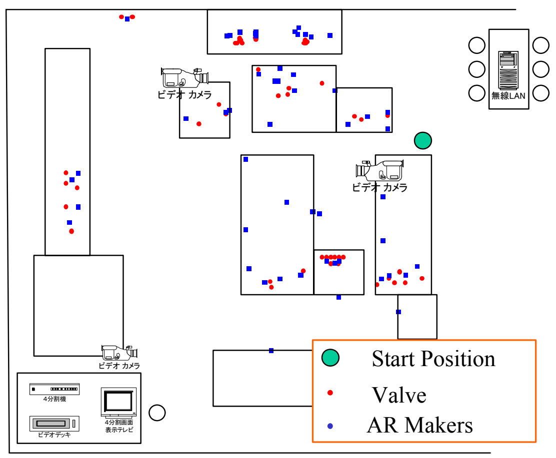


Figure 7. Top view of experimental environment.

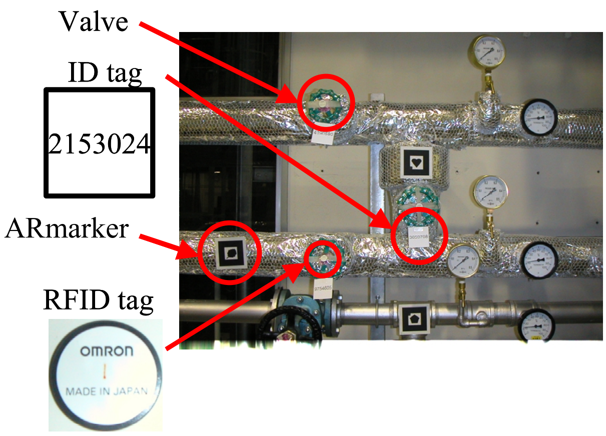


Figure 8. Example of RFID tag and AR marker.

5.2.2 Experimental System

The support system to be used in the experiment is the same as that mentioned in 4.2. The information presentation devices can be replaced to one of the devices shown in Table 1 except tablet PC. When using tablet PC, the laptop PC, video converter and information presentation device is replaced to tablet PC and all the software is installed in it. When the user use the support system, the valve to be found is indicated as the yellow circle virtual object on the user's view in case that it is in his/her view. On the other hand, in case that the valve is out of his/her view, the direction to the seeking valve is indicated corn shape virtual object on one of the AR markers in his/her view. Figure 9 shows an example of the user's view.

5.2.3 Experimental task

The unit task to be given to the subjects is to find 10 designated valves one by one among 50 valves in the experimental environment as the following procedure:

(1) The subject stand at the starting position as shown in Figure 8.
(2) He/She looks for the designated valve with the navigation by the support system.
(3) After finding the valve, he/she confirms whether the found valve is correct or not by using the RFID scanner and the RFID tag attached on the valve. Then he/she points out the found valve and the experimenter confirms whether it is correct or not.
(4) If it is correct, the experimenter tells him/her to move to the next valve until all of 10 valves are found.
(5) If it is not correct, he/she looks for the valve again.

The authors had prepared 9 different valve patterns as 9 unit tasks, however, the optimized tracks of all the valve patterns are the same because the walking time when finding the valves in each task should be the same.

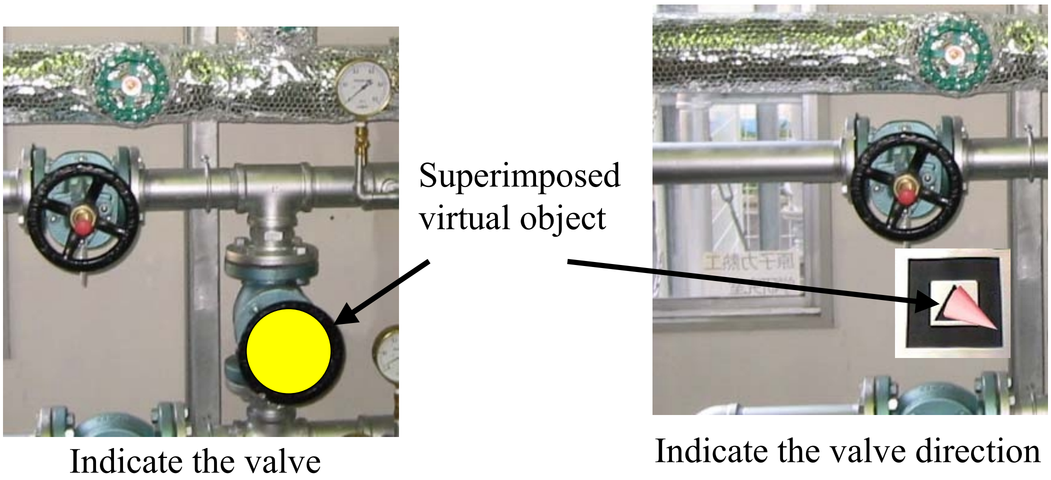


Figure 9. An example of superimposed virtual objects on the user's view

5.2.4 Evaluation Methods and Measurement Indexes

The evaluation methods and measurement indexes to evaluate the information presentation devices are as follows:

(1) Task completion time:
The time to complete the given unit task (to find and confirm all the 10 valves). This is measured by the experimenter using a stopwatch.
(2) Number of errors:
Number of errors when the subject pointes out the valve in a task. This is measured by the experimenter.
(3) NASA-TLX:
NASA-TLX (Hart, 1988) is measured after finishing the task to evaluate the mental workload of the subject in the task. This is measured by Japanese version of computer software (Haga, 1996) installed on a PC.
(4) Usability questionnaire:
The subject fills out a questionnaire about the usability of the device after finishing the task. The questionnaire asks (a)understandability, (b)operability, (c)comfort, (d)total evaluation with 5

scale answers, and his/her impression about advantage/disadvantage of the device by free description. Table 3 shows the questions of the questionnaire. Since original questionnaire used in the experiment is written in Japanese, they are translated into English in Table 3.

Table 3. Questions of Questionnaire

Number	Question	Purpose
Q1	Do you need to learn a lot of things to use this system?	Understandability
Q2	Do you think that various functions of this system are well integrated?	Operability
Q3	Do you think that this system is unnecessarily complex?	Operability
Q4	Do you think it is easy to understand how to use this system?	Understandability
Q5	Do you think this system is useful to find valves?	Total evaluation
Q6	Do you feel it is comfortable to operate this system?	Comfort
Q7	Do you feel it is comfortable to were this system?	Comfort
Q8	List up the advantages of this system.	Advantage
Q9	List up the points to be improved of this system.	Disadvantage

Q1-7: Answer with one of 5 grades, 5:Completely agree – 1:Completely disagree.
Q8,9: Free description.

5.2.5 Experimental Procedure

The experiment is conducted in two stages (I) and (II). In the stage (I), SCOPO and Glasstron are compared, and SCOPO, tablet PC and compact TV are compared in the stage (II). Since the Dataglass2 is not used in the experiment because it had been found that Dataglass2 had a fatal disadvantage in a pre-experiment conducted in advance. It is that the navigation information such as the yellow circle virtual object and the corn shape virtual object cannot be displayed in the correct position of the user's view when the head-mounted device slipped down even 1 millimeter. The authors, therefore, omitted Dataglass2 from the candidates in this experiment.

Both the stage (I) and (II) in the experiment consists of the following steps;

(1) The subject reads a manual about the experiment.
(2) He/She practices all of the devices used in the experiment enough to be accustomed to them with conducting a sample task.
(3) He/She conducts the tasks with paper-based instructions and the devices with measuring evaluation indexes.

In the step (3), the sequence of the stage (I) is shown in Figure 10(a), while that of the stage (II) is shown in Figure 10(b). Each task is given to the subjects randomly among prepared 9 unit tasks, and they do not conduct the same task more than twice.

Task with paper-based instruction	Task with device 1	Task with device 2	Task with device 1, NASA-TLX, Questionnaire	Task with device 2, NASA-TLX, Questionnaire	Task with paper-based instruction

(a) Sequence of the stage (I)

Task with paper-based instruction	Task with device 1	Task with device 2	Task with device 3	Task with device 1, NASA-TLX, Questionnaire	Task with device 2, NASA-TLX, Questionnaire	Task with device 3, NASA-TLX, Questionnaire	Task with paper-based instruction

(b) Sequence of the stage (II)

Figure 10. Sequence of stage (I) and (II).

In Figure 10(a), device 1 and 2 are assigned to SCOPO and Glasstron depending on the subjects. This means that half of the subjects use SCOPO and Glassstron as device 1 and 2 respectively, while other half of the subjects use Glasstron and SCOPO as device 1 and 2 respectively. This assignment should be done because of canceling order effect of the tasks and devices. In the stage (II), device 1, 2 and 3 are assigned to SCOPO, tablet PC and compact TV depending on the subjects as well as the case of the stage (I). The tasks using each device are conducted twice.

Task completion time and number of the errors are measured during all of the tasks, while NASA-TLX and questionnaire are measured only just after the task using the devices in the second time. The case of "task with paper-based instruction" shown in Figure 10 means that the subjects conduct the task with paper-based instruction sheet and a valve location map. A list of the valve ID is written on the paper-based instruction sheet and the locations of all the valves are written on the map with their valve IDs. The subjects look for the valve referring the instruction sheet and the map one by one instead of using the support system. This task is conducted at the first and the last of the sequence because it should be confirmed that there is no learning effect of the task and fatigue effect during the sequence of the stage by comparing the task performances between the first task and the last task.

5.2.6 Subjects

12 subjects (A-L) joined the experiment. They are university students at age from 19 to 24 (average 22.0), 11 of males and a female. They have no experience of water system isolation task. 4 of them wore contact lenses during the experiment. They have no ametropia and no achromatopsia after corrected eyesight.

5.3 Result of Stage (I)

5.3.1 Task Completion Time

Figure 11 shows the average of the task completion times between the first time and the second time for each subject and the average of all the subjects. The horizontal axis means the subject and the average of all the subjects, while the vertical axis means the average of task completion times between the first time and the second time using each device. Before calculating the average of task completion time, it was confirmed that there is no obvious difference between the average time using the devices in the first time and that in the second time ($p<0.05$, t-test). This means that the practice before the experiment was enough and there is no learning effect for the devices. In addition, it was also confirmed that there is no obvious differences between the average time using paper-based instruction in the first task and the last task ($P<0.05$, t-testt). This means that there is no learning effect for the task itself and no fatigue effect for the experimental period.

The result shows that the task completion time when using SCOPO is shorter than that of Glasstron ($p<0.05$, t-test).

5.3.2 Number of Errors

There is no error in all the tasks for all the subjects.

5.3.3 NASA-TLX

Table 4 shows NASA-TLX scores when using SCOPO and Glasstron for all the subjects. The NASA-TLX scores are subjective degrees according to the subjects' own evaluation standard. Therefore, their scores cannot be compared directly. As shown in Table 4, 8 subjects out of 12 evaluated that the mental workload when using SCOPO was less than that using Glasstron (subject B,C,D,E,I,J,K and L).

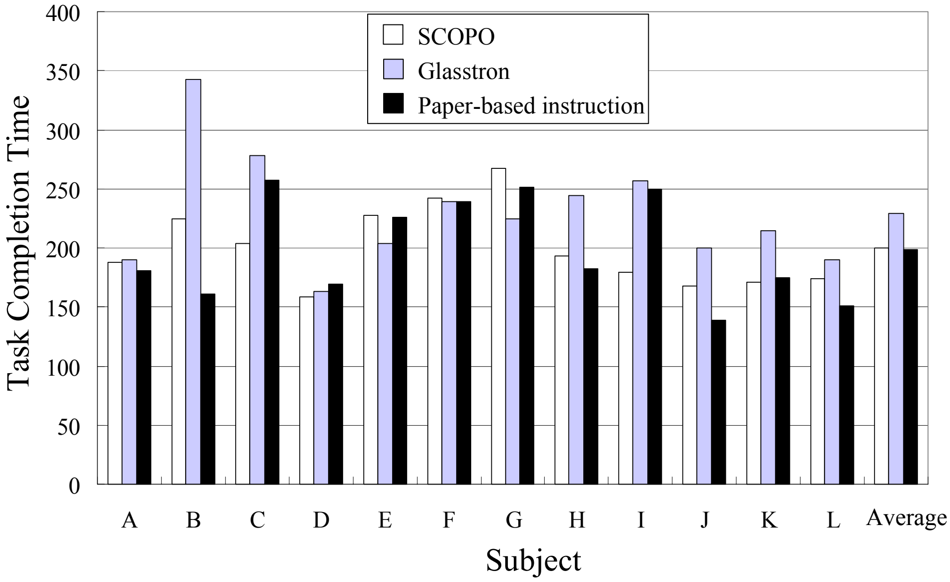


Figure 11. Result of task completion time in stage (I).

Table 4. NASA-TLX Scores when using SCOPO and Glasstron

Subject	A	B	C	D	E	F	G	H	I	J	K	L	Average
SCOPO	69.8	52.3	22.9	45.4	66.8	38.7	67.1	57.5	66.3	19.7	49.1	16.0	47.6
Glasstron	18.1	64.7	43.1	47.3	81.5	31.5	31.3	32.2	71.2	44.3	75.6	61.3	50.2

5.3.4 Usability Questionnaire

Figure 12 shows the results of usability questionnaire in the stage (I). Because Q1 and Q3 are reverse questions, the results shown in Figure 10 are the values subtracted from 6. The values mean the average of the answers, while the error bars mean their standard deviations.

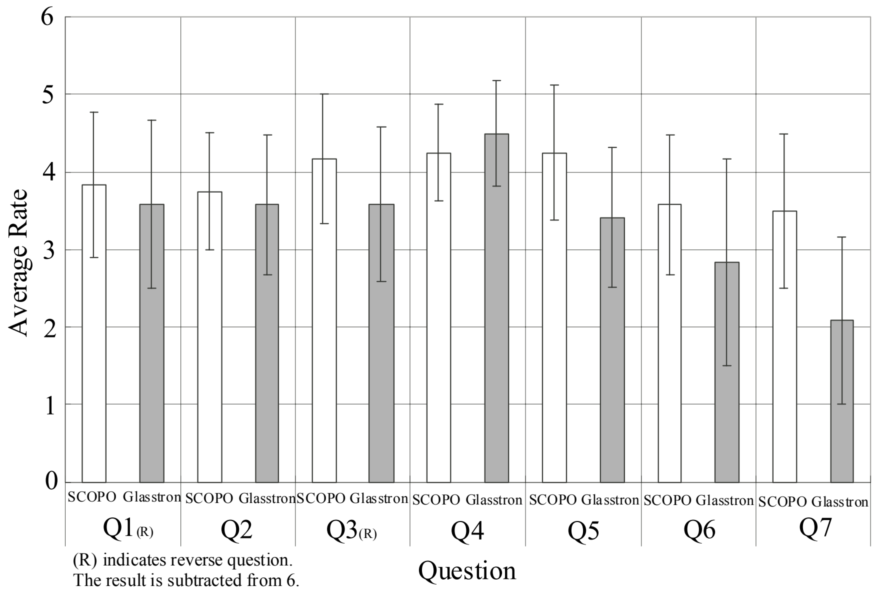


Figure 12. Result of usability questionnaire in stage (I).

Major answers of free description for each device are shown in Table 5.

Table 5 Major answers of free description in stage (I)

Device	Major Answers
SCOPO	Easy and safe to move because the user can see outside view naturally. Eyes were tired.
Glasstron	Easy to use in the beginning. Narrow view. Sense of distance of the display view is different from that of real world. Difficult to move.

5.4 Result of Stage (II)

5.4.1 Task Completion Time

Figure 13 shows the average of the task completion times between the first time and the second time for each subject and the average of all the subjects. Before calculating the average of task completion time, it was confirmed that there is no obvious difference between the average time using the devices in the first time and that in the second time ($p<0.05$, t-test). This means that the practice before the experiment was enough and there is no learning effect for the devices. In addition, it was also confirmed that there is no obvious differences between the average time using paper-based instruction in the first task and the last task ($P<0.05$, t-test). This means that there is no learning effect for the task itself and no fatigue effect for the experimental period.

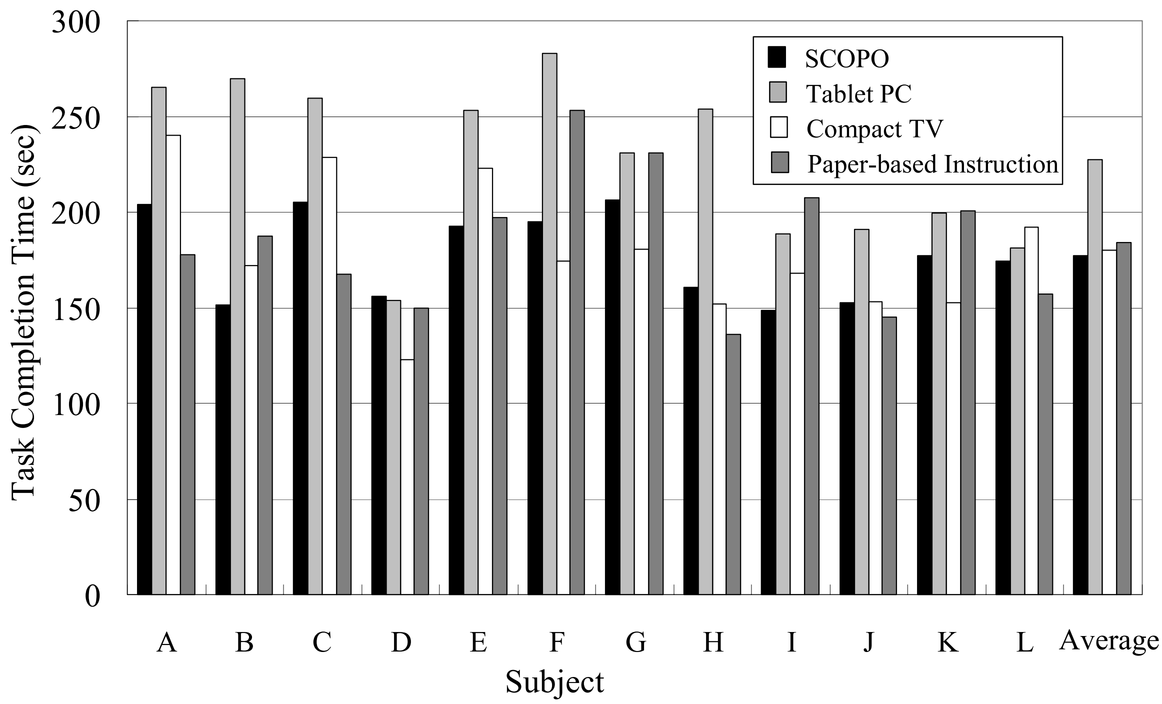


Figure 13. Result of task completion time in stage (II).

As the result, there is no obvious difference between the task completion time when using SCOPO and that of compact TV ($p<0.05$, t-test). The task completion times when using SCOPO and compact TV are shorter than that of tablet PC ($P<0.05$, t-test).

5.4.2 Number of Errors

There is no error in all the tasks for all the subjects.

5.4.3 NASA-TLX

Table 6 shows NASA-TLX scores when using SCOPO, tablet PC and compact TV for all the subjects. As shown in Table 6, 10 subjects out of 12 evaluated that the mental workload when using compact TV was less than both those using SCOPO and tablet PC (subject A, B, C, D, E, F, H, I, K and L).

Table 6. NASA-TLX Scores when using SCOPO, tablet PC and compact TV

Subject	A	B	C	D	E	F	G	H	I	J	K	L	Average
SCOPO	53.7	55.3	37.6	46.3	74.7	20.1	39.3	59.9	58.0	10.4	66.4	46.0	47.3
Tablet PC	57.6	70.7	34.5	62.7	67.6	22.9	69.3	86.5	81.1	57.3	66.9	64.0	61.8
Compact TV	17.2	50.0	15.7	46.1	63.5	14.3	50.0	58.7	38.7	34.4	34.5	24.7	37.3

5.4.4 Usability Questionnaire

Figure 14 shows the results of usability questionnaire in the stage (II). Because Q1 and Q3 are reverse questions, the results shown in Figure 12 are the value subtracted from 6 as well as Figure 12. The values mean the average of the answers, while the error bars mean their standard deviations.

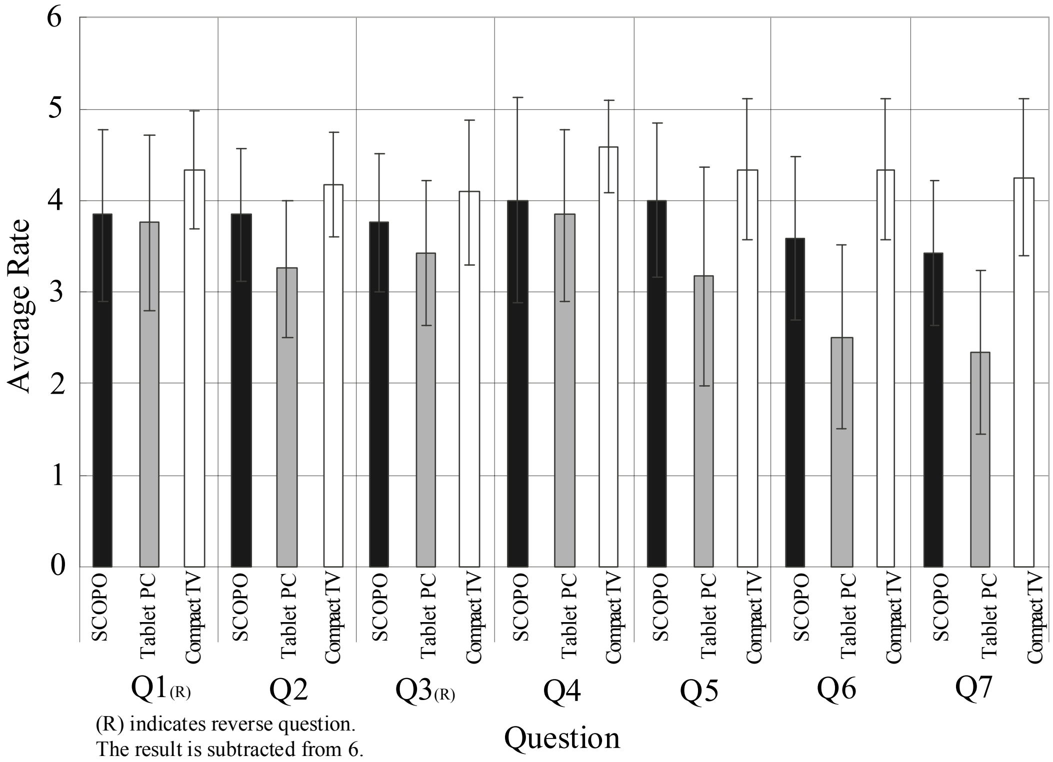


Figure 14. Result of usability questionnaire in stage (II)

Major answers of free description for each device are shown in Table 7.

Table 7. Major answers of free description in stage (II)

Device	Major Answers
SCOPO	Easy to operate because both hands are free. No anxiety when moving.
Tablet PC	Easy to see because the display is large. Heavy to carry.
Compact TV	Light to carry. Employs both hands. Cable between compact TV and laptop PC is troublesome.

6. DISCUSSIONS

6.1 Discussions of Experiment Stage (I)

SCOPO was evaluated higher than Glasstron according to the results of task completion time, NASA-TLX scores and usability questionnaire except Q4. Q4 is "Do you think that this system is easy to use?" and it asks understandability. As mentioned in subsection 5.1, the subjects should switch their view direction between outside view and a display when using SCOPO. When using Glasstron, they do not need to switch their view direction so that Glasstron was easy to use in the beginning. The results of other questions except Q4, however, shows that SCOPO got higher score than Glasstron. According to the free description of usability questionnaire, the subjects' outside view was restricted to only its display area when wearing Glasstron, so that they felt uneasy and sometimes dangerous to move in the experimental environment. This is a fatal disadvantage of Glasstron. In conclusion, SCOPO is more suitable than Glasstron as an information presentation device of wearable configuration.

6.2 Discussions of Experiment Stage (II)

Tablet PC got lower evaluation according to the results of task completion time, NASA-TLX score and usability questionnaire comparing with other devices. From the results of free description of usability questionnaire, it was found that the problem of tablet PC was its heavy weight to carry. Especially, in case that the designated valve is located at high position, the subjects had to lift it up and this was heavy physical load for them.

On the other hand, compact TV got higher evaluation according to the results of task completion time, NASA-TLX score and usability questionnaire comparing with other devices. From the results of free description of usability questionnaire, it was found that the major advantages of compact TV were lightweight, easy to carry, and easy to use. The disadvantage is that the cable between compact TV held in their hand and laptop PC on their back was troublesome.

In conclusion, compact TV is more suitable than tablet PC as an information presentation device of handheld configuration.

6.3 Discussions of Wearable Configuration and Handheld Configuration

From the results of stage (II), there is no difference of task completion times between SCOPO and compact TV, however, NASA-TLX score and results of usability questionnaire of compact TV are better than those of SCOPO. The subjects were asked, "which device is the most effective?" after the experiment, and 8 subjects out of 12 answered compact TV, while 4 subjects answered SCOPO. It can be said that the handheld configuration using compact TV is the most suitable device in the candidate devices from these results.

In this experiment, however, valve operation that uses both hands was not included in the task. If the valve operation is included in the task, the handheld device should be released from the user's hand and it may cause reduction of task performance. Therefore, it cannot be said that the handheld configuration is more suitable than wearable configuration as the support system for water system isolation task.

6.4 Discussions of Overall Experimental Results

The tasks referring a paper-based instruction and a valve location map were conducted as the first task and the last task in both stage (I) and (II) experiment. Since their order effect was not cancelled, the results of paper-based instruction cannot be compared directly with those of other devices. As one of the reference of the results, the task completion time when using paper-based instruction was almost the same as those of SCOPO and compact TV. This does not mean that the task performance of paper-based instruction is the same as that when using the support system because field workers do not have valve location map in real situation. In addition, the real plant environment is so huge that the field workers cannot find the designated valve even if they have a valve location map, and the workers still find the valve depending on their experience. It is supposed that the support system is useful especially in case that they do not have much experience and do not know much about valve locations.

In this experiment, there was no error to find the valves for all the tasks. This is because the subjects confirmed the valve by using the RFID scanner and RFID tags attached on the valves. This means that valve confirmation by RFID is effective to reduce human error when finding the designated valves.

7. CONSLUSIONS

Aiming at improvement of task performance and reduction of human error in water system isolation tasks of NPP periodic maintenance, a support system using AR and RFID has been proposed, and a prototype system has been developed. When applying the system to practical use, the information presentation device of the system is important because it affects the task performance. In this study, therefore a suitable information presentation device has been pursued by conducting subject experiments employing psychological experimental technique.

As the results of the experiment in this study, it was found that one-eye video see-though head mounted display, SCOPO, was suitable device as wearable configuration, and compact TV was suitable device as handheld configuration.

Although the result of task performance and usability of compact TV was better than SCOPO, it can not be said which is better between wearable configuration and handheld configuration because the tasks conducted in the experiment did not include valve operation which used both hands. In the future, evaluation experiments should be conducted with real situation in real plant field.

AR effect was realized by ARToolKit in this study, however, it needs lots of AR markers pasted on the environment. In addition, positions of all the AR markers and the valves in the environment should be registered in the system in advance, and this is troublesome work. This problem should be solved for practical use of this support system by developing appropriate tracking technology in the future.

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