Development and evaluation of a dismantling planning support system based on augmented reality technology

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Abstract: For this study, a Dismantling Planning Support System (DPSS) based on Augmented Reality technology was developed. Its effectiveness and applicability to a real working field were evaluated using a subjective experiment. The DPSS operators can simulate how to locate scaffolding and temporary enclosures (greenhouses) in a real dismantling field in order to decide their layout and to predict the amounts of necessary parts. An interview and questionnaire survey were conducted with Fugen Decommissioning Engineering Center (DEC) staff and a human interface expert, who used DPSS along with a scenario in which scaffolding and greenhouses were located in a turbine cooling water room of Fugen DEC. The experimental results show that the operation for locating the virtual scaffolding and greenhouses using marker boards is intuitive and comprehensive. However, additional research needs to be undertaken in order to improve the DPSS, particularly with respect to its graphical user interface.
Keywords: augmented reality; planning, nuclear plants; computer aided work; 3D CAD models

1 Introduction

After the service period of a nuclear power plant terminates, the nuclear power plant must be decommissioned. However, specific parts of the nuclear power plant remain radioactive. For this reason, the decommissioning procedure of a nuclear power plant differs from those of general industrial plants. To reduce field workers' scattering of radioactive waste as well as their exposure to it, a detailed dismantling plan must be made, with dismantling conducted in a safe way.

In this study, the authors specifically examine a support system for field workers who prepare to dismantle nuclear facilities. For a dismantling plan, it is necessary to decide how to locate scaffolding and temporary enclosures (greenhouses) and to predict the amounts of their necessary parts. To date, expert workers have made decisions and predictions based on their extensive experience. However, numerous expert workers are approaching retirement. Therefore, it is necessary to support novice workers in order to help them make decisions and predictions without the assistance of expert colleagues with extensive experience.

This study develops and evaluates an Augmented Reality (AR) system to support field workers in developing a dismantling plan for a nuclear facility. Application of AR technology makes users feel that virtual objects and symbols actually exist by superimposing computer-generated images on the user's view[1]. For this study, the authors developed a Dismantling Planning Support System (DPSS) that enables field workers to simulate a layout of scaffolding and greenhouses using AR technology in actual dismantling circumstances. Field workers can lay out virtual scaffolding and greenhouses by manipulating "marker boards" representing the type, position, and size of these virtual scaffolding and greenhouses. The positions and orientations of the marker boards are measured in real time and three-dimensional Computer Aided Design (CAD) models of the scaffolding and greenhouses are superimposed, using AR technology, on the workers' field of view.

It is expected that, using DPSS, the field workers can simulate the scaffolding and greenhouse layout

Received date: July 26, 2010
(Revised date: November 24, 2010)

more easily than when using the traditional Graphical User Interface (GUI) because they can represent their mental pictures of the layout of the scaffolding and greenhouses intuitively by manipulating the marker boards, which are real-world objects. They can refer to the current layout candidate using the superimposed view directly in an actual dismantling field.

2 Related works

The literature includes reports of several studies whose objective is to support field workers through the use of AR technology. Schwald *et al.* proposed an AR system called STARMATE for training and assistance in maintaining equipment [2]. Schall *et al.* presented an AR system targeted at aiding field workers of utility companies in outdoor tasks [3]. In order to apply AR to support of field workers in nuclear power plants (NPPs), Piotrowski *et al.* proposed that AR is useful to visualize a dose map to improve radiation awareness [4]. Shimoda *et al.* developed a support system for a water system isolation task using AR technology and evaluated it using a subjective experiment [5]. Ishii *et al.* proposed and evaluated a support method for NPP decommissioning work using AR[6]. All of these studies aimed at providing rich information about maintenance work to field workers by superimposing computer graphics over their field of view. All make it possible for workers to complete their assignments in less time and with fewer errors.

This study intends to provide an intuitive user interface for simulating a layout of scaffolding and greenhouses by manipulating real-world objects and viewing the layout candidates using AR technology. More specifically, the authors show that a marker-based tracking method, combined with an interface using markers as an interactive medium between users and a computer, produces a simple interactive simulation environment that can be applied to an actual working field.

3 System design

3.1 System requirements and basic design

For this study, the following system requirements were identified as the foundation for DPSS development:

(a) Ease of bringing the DPSS to and from the dismantling field.
The DPSS is meant to be used in an actual dismantling field instead of a simulated one. Because the real dismantling field is frequently modified, it is difficult to keep the simulated dismantling field updated to represent the actual dismantling field. Therefore, the DPSS must be compact and easy to set up and remove even if the dismantling field is crowded with many obstacles.

(b) Ease of changing the layout target position, orientation, and size.
It is difficult for field workers to change the three-dimensional position, orientation, and size of the layout targets with the traditional interface generally used in CAD applications. Changing the layout must be easier and more intuitive. However, its accuracy must remain sufficient in order to ensure its practical use.

(c) Ease of referral to the current layout candidate.
Not all workers who will use the DPSS are familiar with 3D CAD representations such as orthogonal views. Therefore, the method of referring to the current layout candidate must be easier and more intuitive than the traditional representation.

(d) Ease of recording the result of the layout simulation.
The result of the layout simulation is meant to be used as a basis of official documents related to the dismantling plan. The result will also be used to share the dismantling plan among field workers. In order to simplify these activities, it is essential for the result of the layout simulation to be easily recordable.

A display device allowing operators to view the current layout candidate is indispensable for the use of a DPSS. The device should be as small as possible to meet system requirement (a). However, a subjective experiment confirmed that a head mounted display (HMD) is inadequate for use in the field because it might obstruct the worker's view[5]. Furthermore, a small display such as that of a PDA is also inadequate because its screen is too small to view the current layout candidate. Therefore a tablet PC is used. However, due to its weight, the tablet PC cannot be held for a long time, implying that it must be mounted on a tripod.

To meet system requirement (b), a type of real-world-oriented interface enabling users to control a computer by manipulating real-world objects is used, as presented in Fig. 1. The type of real-world object is linked to the kinds of scaffolding and greenhouses. Three real-world objects are used to represent the position, orientation, and size of the scaffolding and greenhouses. A vector between the positions of two real-world objects represents the position, width, and direction of the scaffolding and greenhouses; the last real-world object represents their height. Field workers can change the layout by manipulating the real-world objects.

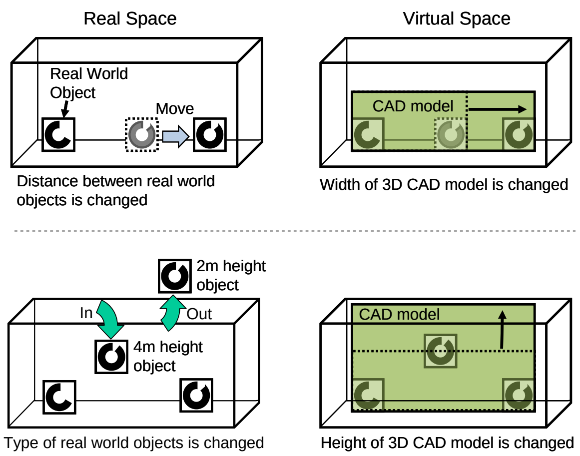

Fig. 1 Interaction using real-world objects. The 3D CAD model width is modified by changing the distance between the real-world objects (up). Changing the type of real-world objects changes the 3D CAD model height (bottom).

To meet system requirement (c), AR technology is used. The dismantling field is captured using a camera. Then the current layout candidate is superimposed on the camera image so that 3D CAD models are resized and located accurately according to the real-world object position. This accurate superimposition is realized automatically, even if field workers change the real-world object position.
To realize the real-world-oriented interface and the AR effect described above, a tracking technique that measures the three-dimensional position of the real-world objects and the camera in real time is indispensable. However, existing tracking methods such as Global Positioning Systems, magnetic sensors, ultrasonic sensors, and inertial sensors can not be used in NPPs. Therefore, a tracking method proposed by Ishii *et al.*[7] was used. After a camera captures the markers, the ID of the markers and their position on the camera image are recognized using image processing techniques. Subsequently, the relative position and orientation between the markers and the camera is calculated using Perspective-N-Point (PnP) solutions.

Using the tracking method, two tracking modes are available. Camera tracking calculates the position and orientation of a camera relative to the marker cluster pasted in the environment. Marker tracking calculates the position and orientation of a marker relative to a camera. With simultaneous use of camera tracking and marker tracking, the position and orientation of the marker relative to the marker cluster pasted in the environment are obtainable. To execute camera tracking, the marker cluster position and orientation must be measured in advance. An Automatic Marker Registration System (AMRS) can perform this measurement automatically, as proposed by Yan et al. [8].

The position and orientation of the DPSS camera are tracked with the camera tracking method. On the other hand, a marker is pasted on a board as a real-world object. Its position and orientation are tracked using marker tracking. System requirement (d) can also be met, as it is easy to record the simulation result and calculate the amount of necessary parts when accurate positions of the marker boards are obtainable.

3.2 Working procedure design using DPSS

Figure 2 presents a conceptual framework of the DPSS used for the layout simulation. The simulation is conducted by two workers (a system operator and a board operator). The system operator uses a tablet PC that displays the current layout candidate on its two-dimensional screen. The board operator locates the marker boards and changes their position according to directions given by the system operator. The detailed procedure is as follows:

Step 1: Bring DPSS and AMRS to the dismantling field. Workers assemble the parts and connect the cables.

Step 2: Paste the markers in the dismantling field and measure their positions and orientations using AMRS. These markers are used for camera tracking.

Step 3: Disassemble and remove AMRS.

Step 4: The board operator locates the marker boards where scaffolding and greenhouses are positioned.

Step 5: Capture the dismantling field, including markers pasted in the environment and the marker boards. The 3D CAD models of the scaffolding and greenhouses are superimposed on the camera image according to the marker board type and position.

Step 6: The system operator gives directions to the board operator to change the marker board type and position.

Step 7: Repeat Steps 4 to 6 until sufficient scaffolding and greenhouses are located and their layout is satisfactory.

Step 8: Record the simulation result. At this time, not only the position, orientation, and size of the scaffolding and greenhouses, but also the amounts of their respective necessary parts are calculated and recorded.

Step 9: Disassemble and remove DPSS.

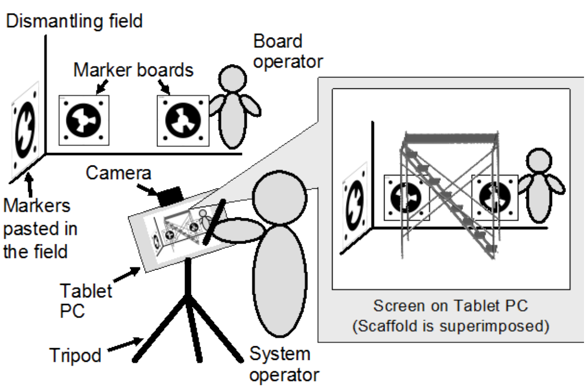

Fig.2 Conceptual framework of DPSS.

3.3 Other system functions

In order to tackle the complexity of dismantling an actual field, some other functions are necessary in addition to the real-world-oriented interface and the AR function described above. There could be situations in which it would be difficult to position the marker boards where the scaffolding and greenhouses should be located, for example because of a setting that would be too high or otherwise inaccessible. In that case, it should be possible to change the layout without manipulating marker boards. Furthermore, a case in which the scaffolding or greenhouses must be removed after being located in the field could also be encountered.

One way to execute these operations is to define new marker boards that are specialized for such operations. For example, it is technically possible to define a marker board as specialized for the removal of located layout targets. The field worker can eliminate the located layout targets by showing the special marker board to the DPSS camera. However, in this case additional markers must be defined. Moreover, this operation is not intuitive. Therefore, it would be better to render it possible for field workers to change and remove the layout targets by operating the tablet PC directly. But since it would be difficult to use a legacy mouse in the dismantling field, this system would instead use a stylus pen. This is an electrical pen—used instead of a mouse— which allows the user to control a computer cursor. The interface metaphor resembles that of a legacy pencil. It is expected that field workers would be able to use the stylus pen easily because they would already be accustomed to using the legacy pencil in their daily work. Functions to move, rotate, resize, and remove objects using a stylus pen will be realized for DPSS.

4 Developed system

Figure 3 shows that the DPSS consists of a tablet PC, a CCD camera, a tripod, and several cables. Table 1 briefly presents some of the technical specifications of the tablet PC and of the CCD camera. The camera images are undistorted using intrinsic camera parameters obtained with the GML camera calibration tool box[9]. The marker boards are 32 × 32 cm. A 15-cm-radius marker is printed on the marker board.

The software was developed using compiling software (Visual C++ 2005; Microsoft Corp.) with an operating system (Windows Vista; Microsoft Corp.). A middleware library for rendering 3D CAD models (TV3D SDK ver. 6; Truevision3D) was used to superimpose 3D CAD models on the camera images.

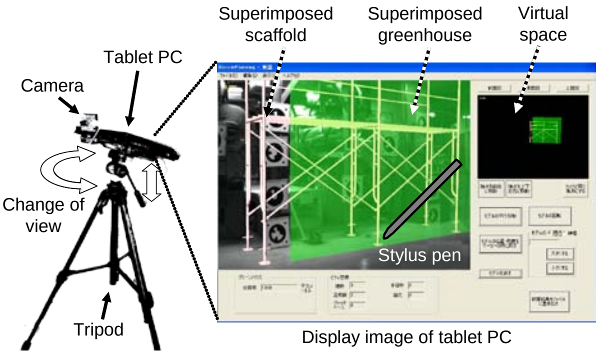

Fig.3 Configuration of DPSS.

Table 1 Hardware Specifications

Tablet PC	Vendor	Lenovo Inc.
	Model	Thinkpad X61 Tablet
	CPU	Core2Duo L7500 1.6GHz
	Display	12.1 inch TFT color LCD (XGA)
	OS	Microsoft Windows Vista Business
	Weight	2.06 kg
Camera	Vendor	Point Grey Research Inc.
	Type	Dragonfly2 HIBW
	Resolution	1024×768
	Color	8bits grayscale
	Frame Rate	30fps
	Lens	BW38B-1000 (f = 3.94mm)
	Weight	0.045 kg

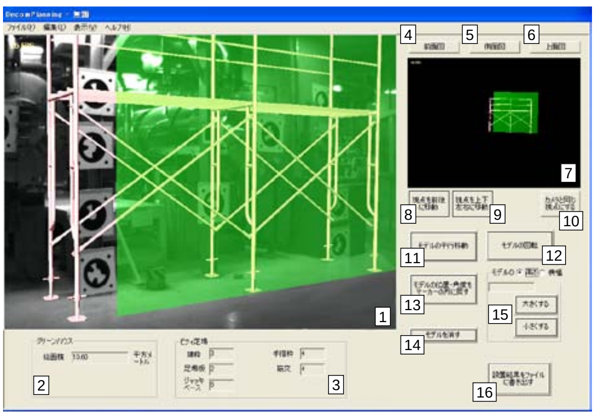

Fig.4 Display image of tablet PC.

Figure 4 shows the tablet PC display image. The system operator views the superimposed image using the interface and operates the tablet PC using a stylus pen to change the layout target position, orientation, and size. Table 2 presents some of the functions of the image display software.

Table 2 Functions of DPSS GUI

No. in Fig.4	Function
1	Camera image is displayed with 3D CAD models superimposed.
2,3	The amount of necessary parts for greenhouses and scaffolds is displayed.
4,5,6	Change the view direction of the virtual space to front, side, or top view.
7	Virtual space with 3D CAD models is displayed.
8,9	Change the mode for adjusting the view direction of the virtual space. After pushing these buttons, the view direction of the virtual space can be changed by dragging the virtual space.
10	Set the view direction of the virtual space to the same direction as the view direction of the camera.
11,12	Change the mode for adjusting the position and orientation of 3D CAD models. After pushing these buttons the position and orientation of 3D CAD models can be changed by dragging the models.
13	Reset the adjustment of the position and orientation of 3D CAD models.
14	Remove specified 3D CAD model.
15	Change the size of 3D CAD model.
16	Save the simulation results to a file.

5 Evaluation experiment

5.1 Objective

The real-world interface and AR technology are expected to make it possible for field workers to simulate the scaffolding and greenhouses layout intuitively. It remains unknown whether each proposed function would be effective or not, how acceptable the system would be for actual field workers, or what problems could arise during its practical use. An evaluation experiment was conducted to answer these questions.

5.2 Method

For this study, a heuristic evaluation method proposed by Nielsen[10] was selected. Evaluators used the DPSS with the assumption that a nuclear power plant facility was dismantled, along with a scenario. Evaluators played only the role of system operator. The experimenter played the role of board operator. After using the DPSS, the evaluators answered a questionnaire prepared according to Nielsen's guidelines. Afterwards, an interview and a group discussion were conducted.

5.3 Dismantling target

Figure 5 shows a turbine cooling water (TCW) system at the Fugen Decommissioning Engineering Center (DEC), which was the dismantled facility in this evaluation.

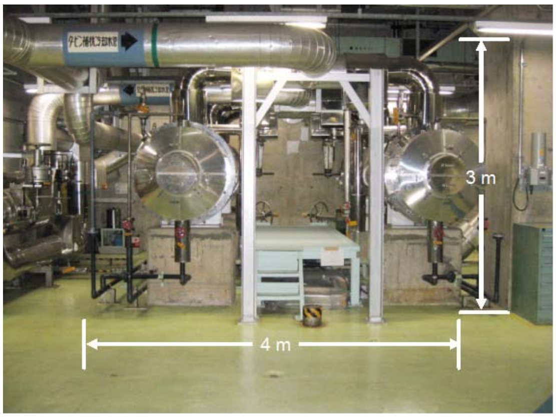

Fig.5 Dismantling target used in the evaluation.

5.4 Evaluators

Of the four evaluators, three (Evaluators A, B, and C) were Fugen DEC staff. One (Evaluator D) was a human interface expert working at a university.

5.5 Evaluation procedure

Before the evaluation, the experimenter pasted markers in the environment and measured the position and orientation of the markers using AMRS. The experimenter explained only the basic concept of DPSS to the evaluators. The experimenter did not explain how to use DPSS in detail. Evaluators were allowed to ask questions to the experimenter when they could not determine how to use the function of DPSS during the evaluation.

The evaluation procedure was the following:

(1) Place the tripod in a location where the entire TCW system can be viewed. Fix the tablet PC on the tripod and connect a cable between the tablet PC and the camera (the camera was fixed on the tablet PC in advance).

(2) Double click an icon on the tablet PC desktop with the stylus pen to launch the DPSS application.

(3) Consider the scaffolding and greenhouses layout that is adequate for dismantling the TCW system.

(4) Decide the layout of the scaffolding and greenhouses using DPSS. It was requested that at least three greenhouses and one scaffold be located. It was also requested that functions be used to adjust the position, orientation, and size of the scaffolding and greenhouses using both the stylus pen and the marker boards.

(5) Save the simulation results in a file and disassemble the DPSS.

(6) Fill out the questionnaire and join the group discussion.

5.6 Questionnaire

Table 3 shows that the questionnaire includes 33 items, targeting system function and usability, based on guidelines of the heuristic evaluation method. Evaluators answer each question as 1–5 (1, completely disagree; 2, disagree; 3, neither agree nor disagree; 4, agree; 5, completely agree). In addition, an open space is provided at the end of the questionnaire, where respondents can describe other problems and suggest areas that need to be improved.

5.7 Results

Each evaluator used DPSS for approximately 30 to 40 minutes. Table 3 presents the results of the questionnaire. Table 4 presents the answers collected from the open space at the end of the questionnaire, the interview, as well as the group discussion.

5.8 Discussion

Evaluator D gave a negative response to Q1. Evaluator D also gave a negative comment (D1) for Q1. The cause of the low evaluation for Q1 was probably that the marker tracking can sometimes be unstable. To improve the marker tracking stability, it is necessary to use a new camera with higher resolution, instead of increasing the size of the markers, because it is difficult to use larger markers in an actual NPP field.

Table 3 Questionnaire results

	Questionnaire	Evaluator			
		A	B	C	D
Q1	Can you locate scaffolds and greenhouses in the places where you would like to?	4	3	3	2
Q2	Is it clear that you can see scaffolds and greenhouses superimposed in your view?	5	4	5	4
Q3	Is it effective to be able to save the results of placing scaffolds and greenhouses in a file?	5	5	5	4
Q4	Is it easy to change the position, orientation, width, number of scaffolds and greenhouses by moving marker boards?	4	3	5	5
Q5	Is it easy to change the height of scaffolds and greenhouses by changing marker boards?	4	3	5	4
Q6	Is it effective to change the position and orientation of scaffolds and greenhouses by changing the position of the marker boards?	4	5	5	4
Q7	Is it effective to change the width of greenhouses by changing the position of the marker boards?	4	4	5	3
Q8	It it effective to change the number of the scaffolds by changing the position of the marker boards?	4	4	5	3
Q9	Is it effective to change the height of the scaffolds and greenhouses by changing the marker boards?	4	4	4	2
Q10	Is it easy to select scaffolds and greenhouses using a stylus pen?	4	3	3	5
Q11	Is it easy to move scaffolds and greenhouses in parallel using a stylus pen?	3	3	4	5
Q12	Is it effective to move scaffolds and greenhouses in parallel using a stylus pen?	3	4	5	5
Q13	Is it easy to rotate scaffolds and greenhouses using a stylus pen?	3	3	2	1
Q14	Is it effective to rotate scaffolds and greenhouses using a stylus pen?	3	4	5	5
Q15	Is it easy to do the detail operation by stylus pen?	4	2	2	4
Q16	Is it easy to remove scaffolds and greenhouses?	4	3	5	5
Q17	Is it effective to remove scaffolds and greenhouses?	4	4	5	4
Q18	Is it easy to change the number of scaffolds and the size of greenhouses using a button?	4	3	5	4
Q19	Is it effective to change the number of scaffolds and the size of greenhouses using a button?	4	4	5	5
Q20	Is it effective to move back the position of scaffolds and greenhouses already moved, using a stylus pen?	4	4	5	4
Q21	Is the camera view (upper left) comprehensive?	3	3	3	1
Q22	Is it easy to operate scaffolds and greenhouses in the operation view (upper right)?	3	3	2	2
Q23	Is the correspondence between the camera view and the operation view clear?	3	3	2	2
Q24	Is it effective to save the area of greenhouses and the number of scaffolds?	5	4	5	5
Q25	Is it easier to estimate the area of greenhouses and the number of scaffolds with the system than without the system?	5	3	4	-
Q26	Is the estimation of the area of greenhouses and the number of scaffolds with the system more exact than without the system?	5	3	3	-
Q27	Is it clear how to change the color of the selected scaffolds and greenhouses?	5	4	5	5
Q28	Is it easy to rotate the system mounted on the tripod?	3	4	4	4
Q29	Is it easy to carry the system mounted on the tripod?	3	4	4	3
Q30	Is it easy to set up the system?	5	4	4	5
Q31	Is it easy to remove the system?	5	4	4	5
Q32	Is the response of the system quick?	4	3	3	4
Q33	Did you feel any stress while using the system?	3	3	3	4

Table 4 Free description and interview results

Evaluator A	
A1	It is difficult to use the stylus pen. A training period is necessary to become familiar with the pen.
A2	I will not be able to change the width of the greenhouses and number of scaffolds using the marker boards in a narrow space.
A3	The camera view is dark and narrow.
A4	The operation view is too small to operate. It should be possible to operate the models on the camera view.
A5	The system mounted on the tripod is too large to carry, especially in a narrow space.
A6	It is difficult to estimate the depth of the greenhouses and scaffolds.
A7	The camera performance (view angle and brightness) should be improved.
Evaluator B	
B1	It is difficult to use the stylus pen. A training period is necessary to become familiar with the pen.
B2	I will not be able to change the width of the greenhouses and number of scaffolds by the marker boards in a narrow space.
B3	I could not change the height of the greenhouses, sequentially, using the marker boards.
B4	It is sometimes difficult to select the greenhouses and scaffolds using the stylus pen.
B5	It is difficult to rotate the greenhouses and scaffolds.
B6	The camera view is too dark.
B7	The camera view and the operation view are small.
B8	The operation methods should be improved.
B9	It is more intuitive to use the system than to draw the plan on a desk.
Evaluator C	
C1	It is difficult to use the stylus pen. A training period is necessary to become familiar with the pen.
C2	The operation view is too small to operate.
C3	It is difficult to enclose the dismantling target by the greenhouses three-dimensionally.
C4	It is difficult to move and rotate the greenhouses and scaffolds.
C5	It is not clear where the greenhouses and scaffolds are located in the real world.
C6	It would be better if it is possible to locate the scaffolds and greenhouses without the marker boards.
C7	It would be better if it is possible to select camera to make the depth of the world comprehensive.
C8	Pasting many markers in a real working field would not be feasible.
Evaluator D	
D1	The superimposed greenhouses and the scaffolds move unsteadily.
D2	I could not determine the types of the height markers.
D3	It is difficult to rotate the greenhouses and scaffolds.
D4	I could not know how to recover the deleted greenhouses and scaffolds.
D5	Using the buttons, I could not change the size of the greenhouses the way I wanted to.
D6	The camera view is too dark and its view angle is too small.
D7	The operation view is too small to operate.
D8	I could not understand the actual direction of the front view, side view, and top view.
D9	It is a little unstable to move the system.
D10	It is comprehensive to direct the position of the models using the marker boards because it is possible to directly indicate the positional relation between the real world and the virtual world.
D11	It is better that the model of the dismantling target is also visualized in the operation view.
D12	It is better that it is possible to change the position of the camera view and operation view as we want.

Almost all evaluators gave positive responses to Q2 – Q8. These results show that the utilization of AR technology to represent current layout candidate, and of a real-world objects interface to locate greenhouses and scaffolds is adequate. The results are also supported by comments (B9) and (D10). However, the superimposition of the virtual greenhouses and scaffolds on the camera image should be improved because evaluators A and C respectively gave comments (A6) and (C5). For example, we can add the shadows of virtual greenhouses and scaffolds in order to make it possible for the user to catch the depth of virtual objects.

Evaluator D gave a negative response to Q9. Evaluator D was a human interface researcher and had no experience in conducting dismantling work. Therefore it is inferred that evaluator D was not familiar with the possible use of this function. Evaluator D also commented negatively (D2). For this experiment, no visible signs existed on marker boards in order to explain their function to the system operator. Signs that are visible to the system operator and that explain the specific function should be added on marker boards.

All evaluators gave positive responses to Q10 – Q12 and Q14. These results show that the stylus pen is acceptable for selecting and moving the scaffolds and greenhouses. However, it was not easy for the evaluators to rotate the scaffolds and greenhouses using the stylus pen, as indicated by the negative responses to Q13. This point is also supported by the negative comments (B5), (C4), and (D3). The stylus pen was used because it was not expected for the field workers to encounter any difficulty in using it. However, evaluators B and C gave negative responses to Q15. Moreover, evaluators A, B and C gave negative comments about the stylus pen: (A1), (B1), (B4), and (C1) respectively. The metaphor for using the stylus pen is similar to that of the legacy pencil, but the actual operation using the stylus pen differs from that using the legacy pencil and therefore requires some training.

All evaluators gave positive responses to Q16 – Q19, attesting that GUI operation for removing and scaling the scaffolds and greenhouses is easy and effective.

Evaluator D responded negatively to Q21. Evaluator D also commented negatively in (D6). Evaluators A and B commented negatively about the camera view in (A3), (A7), (B6), and (B7). For this evaluation, a lens whose focal length was rather long was used, and the gain was set rather low in order to render the tracking more stable. The camera image could be made brighter by applying contrast enhancement techniques. Both a wide angle view and stable tracking could be achieved using a new camera with higher resolution.

All evaluators responded negatively to Q22 and Q23. Both questions were related to the operation view. They also commented negatively about the operation view in (A4), (C2), and (D7). The main cause was that the operation view was too small. The size of the operation view should be increased.

All evaluators gave positive responses to Q24, showing that the function of qualitative estimation of necessary parts would be effective for the actual dismantling work.

All evaluators gave positive responses to Q25 – Q33. Evaluator D refused to respond to Q25 and Q26 because he had no experience in conducting dismantling work and could not answer properly. These results show that the functions for saving the simulation results, estimating the necessary parts, and moving the system on the tripod are adequate.

Evaluators gave negative comments to other aspects of the system. Evaluators A and B pointed out that it might be difficult to use the system in a small space ((A2), (A5), and (B2)), which would perhaps necessitate smaller marker boards and a lighter tablet PC. The former can be realized by using a new camera with higher resolution. However, the latter point is rather difficult to achieve because a smaller tablet PC would likely have a smaller screen, which will complicate the operation of the DPSS, which relies on the use of a stylus pen. Therefore, the DPSS will have to be limited to usages in large spaces.

Several other comments suggest ideas to improve the DPSS. Evaluator B commented on the method of changing the greenhouse height (B3). For this evaluation, a limited number of markers were prepared for setting the greenhouse height. Therefore, the evaluator was able to set the greenhouse height only in a discrete way. Although the authors inferred that this is sufficient, we should provide another way to set the height sequentially. Evaluator C commented on the process of locating the scaffolds and greenhouses (C6). For this evaluation, the evaluators needed to use the marker board to locate the scaffolding and greenhouses even if they intended to use the stylus pen to later change the layout. A function to locate the scaffolding and greenhouses using only the stylus pen should be provided.

6 Conclusions

This report described a support system for field workers who, using AR technology, prepare the dismantling work of nuclear facilities. It was evaluated by three decommissioning engineering center staff members and one human interface expert. The following results were obtained:

(1) Operation for locating scaffolding and greenhouses using real-world objects is intuitive and comprehensive.
(2) Functions of qualitative estimation of necessary parts are effective for actual dismantling work.
(3) Some operations are difficult. The stylus pen requires practice and the system screen is small.
(4) The operation method and the resolution of the camera should be improved.

Taken together, results confirmed that the use of a real-world interface and AR technology for supporting the preparation of the dismantling work is acceptable but the system itself is not yet sufficiently developed. In particular, the interface should be improved.

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