Distance Information Display System using Augmented Reality for Supporting Decommissioning Work

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Abstract: In this study, Augmented Reality based Distance Information Display System has been developed and evaluated, which can be used with very simple operation. By capturing target objects with a RGB-D camera, the system automatically measures lengths and gaps of the target objects. The system extracts and displays the lengths that workers may want to measure by a heuristic filtering process. An experiment was conducted to evaluate the Distance Information Display System. The experimental results showed that the Distance Information Display System may resolve the problems of manual measurement and reduce the measurement time.

1 INTRODUCTION

More than 400 nuclear power plants (NPPs) are in operation in the world. Some of them are necessary to be dismantled in the near future. In the dismantling work of NPPs, it is sometimes necessary to measure dimensions of objects such as a pipe in order to estimate the total amount of waste. Also, it is necessary to measure gap lengths between equipments to investigate whether there is a sufficient space to install equipments to be used for dismantling. Conventionally, these lengths are measured manually using tape measures or laser measuring instruments. However, manual measurement has a problem that the workers have to measure each length one by one, so much labor is required. On the other hand, there is another method measuring the lengths. In this method, the target objects are captured with a camera which can obtain 3D model of the targets, and the measurement part is specified manually. However, this method also has another problem that it is sometimes difficult to make detail operations because the workers may need to wear gloves to prevent radiation exposure.

The objective of this study is to develop a Distance Information Display System, which can be used with extremely simple operation. The system measures lengths of objects and gaps the workers may want to measure automatically. The interface is based on the Augmented Reality style, which is considered effective in not only NPP decommissioning work but also various industrial areas (Ishii et al., 2007) (Fite-Georgel, 2011). Measured values are shown over the target objects on the system screen, so that the workers can refer the values very intuitively.

2 DEVELOPED SYSTEM

2.1 Overview of the System

With a preliminary interview for dismantling workers of NPPs, it was found that major targets for the measurement in demolition works are the lengths of pipes, gaps between pipes and walls or floor. Therefore, the system should display the lengths of these objects and gaps. With a recent development of measurement technology, it becomes easy to obtain the three-dimensional shape of the plant including the dimensional information(Heung-Yeung Shum, 1999)(Kähler et al., 2016) (Ishii et al., 2011). Figure 1 shows an example of the 3D model. It is therefore easy to obtain the metric information between two arbitrary points. It is also easy to show the metric information if the workers could specify the part to be measured. However, it is difficult for workers to operate the system in detail because the workers sometimes have to wear gloves at the site. Therefore, the system is required to be able to display metric information with as simple operation as possible. The system developed in this

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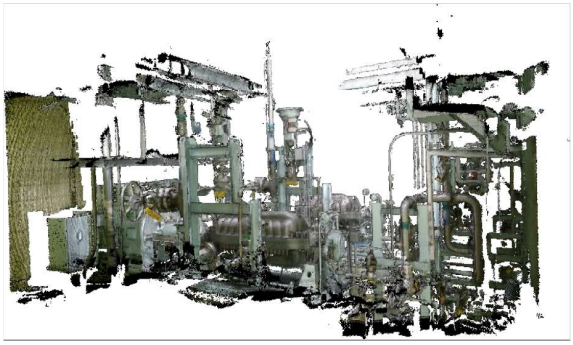

Figure 1: An example of the 3D model.

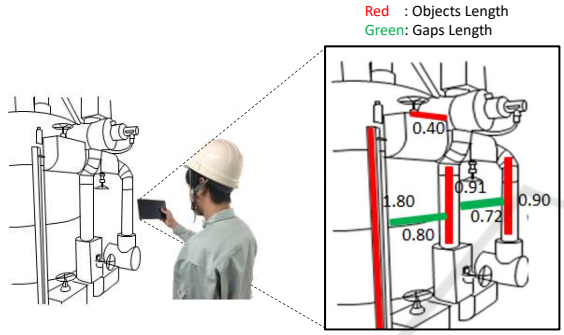

Figure 2: Usage image of the Distance Information Display System.

study allows to show the lengths of the objects and the gaps with extremely simple operation so that the workers wearing gloves can handle easily at the time of disassembling work of NPPs.

Table 1 shows required specifications of the Distance Information Display System. These specifications were decided based on the interview for the dismantling workers of NPPs. Figure 2 shows the usage image of the Distance Information Display System. It may be possible to refer three-dimentional CAD models to obtain distance information, but it is necessary to update the model when the site changes. Accordingly, in order to display correct values even if the sites changes, it was decided to measure the sites using a RGB-D camera which can obtain the metric information of the target object in real time considering the specifications of Table 1.. Candidates of a device displaying metric information were a tablet PC or a head mount display (HMD), such as Microsoft Hollens. Because visibility narrows and risk of some injury or errors increases when NPP decommissioning workers equip a HMD, it can be said that HMD is inappropriate for the displaying device. Therefore, a tablet PC was used as the displaying device. When the target object is captured with a RGB-D camera, the image is displayed on the screen of the tablet PC, the target is automatically measured, and the metric

Table 1: Required specifications of Distance Information Display System.

(A) It is easy to bring the system to the site.
(B) The system do not prevent from the work.
(C) The system do not require complicated operations.
(D) It is possible to accurately measure the intended part.
(E) The display is easy to see.
(F) It is possible to measure in a short time.
(G) It is easy even for people using it for the first time to use.
(H) It is possible to measure even in places that can not reach.

information is superimposed on the displayed target object. However, it is difficult to manipulate the tablet PC because of wearing gloves, so we made it possible to operate the Distance Information Display System with externally attached button only (touch operation on a tablet PC is disabled). From the above, the hardware of the Distance Information Display System consists of a tablet PC, a RGB-D camera, and an external button.

2.2 System Flow

Figure 3 shows the overall flow of this system process. The system sequentially transits 2 modes, photo mode, and length display mode. When the system is started, it first enters the photo mode. In this mode, the RGB image acquired by the RGB-D camera is displayed on the screen of the tablet PC and is updated in real time. When the button is pressed in this mode, the screen stands still. This is because if the screen is constantly updated, it is expected that the measuring portion will be unstable due to camera shake at the time of photographing, which is considered to cause difficulty in measurement. The mode transits to the length display mode, and the measurement results are superimposed on the screen at once.

When the button is pressed in the photo mode, the measurement targets are captured with the RGB-D camera and the RGB image and the depth image are obtained. Line segments in these images are extracted with LSD(Rafael Grompone von Gioi, 2012). Then the lengths of the objects are obtained by getting the three-dimensional coordinates of the ends of the line segments from the depth image. As shown in Figure 4, line segment detection sometimes fail only with the RGB image. This failure may occur when the color near the boundary are similar. However, the lengths of these boundary should be measured. Accordingly, LSD is applied also for the depth image.

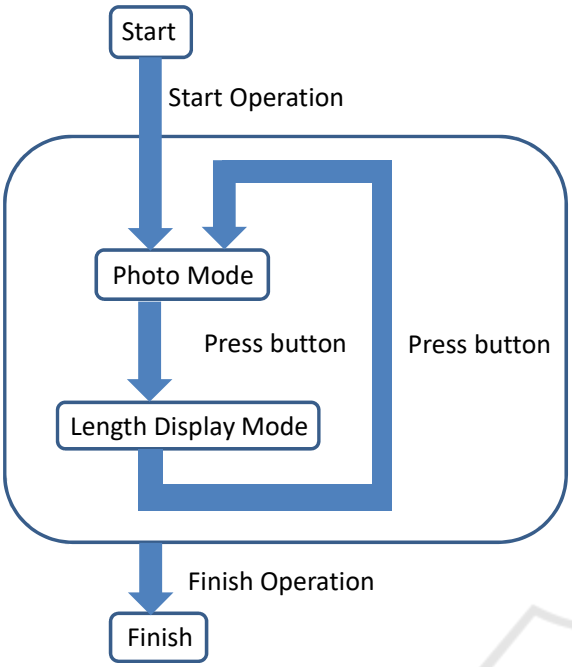

Figure 3: Entire flow of the system process.

Figure 4: An example of the part where a line can not be detected in a RGB image, but can be detected in a depth image.

The line segment at the boundary can be hereby detected stably.

At the same time, the lengths of the gaps are obtained by using the point cloud acquired from the depth image. Below processes are executed to measure the lengths of the gaps.

1. Point cloud is made from the depth image.
2. Planes and pipes in the point cloud are recognized.
3. Lengths of gaps between the planes and the pipes are obtained.

Line segments and their lengths detected by this method are displayed on the screen. However, when all of the line segments are superimposed on the RGB image, it may be difficult to recognize the measurement results. Figure 5 shows an example when all of the extracted line segments are simultaneously superimposed on the original RGB image. Therefore, a filtering function is implemented to decrease the displayed metric information. Based on the below rule,

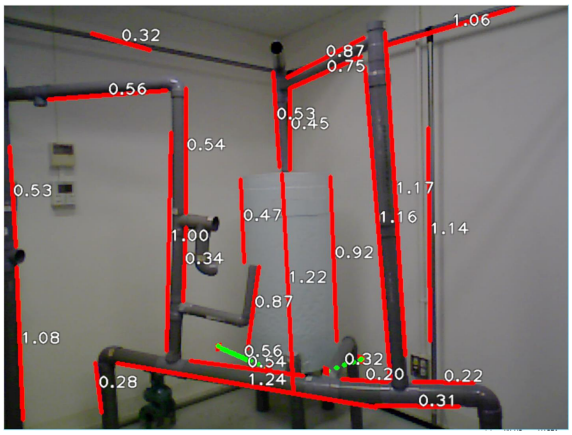

Figure 5: An example when all of the extracted line segments are simultaneously superimposed on the RGB image.

the priority of the metric information is determined .

- In the case that two line segments intersect or are close to each other, either of these line segments is prior to the other.
- The line segment whose depth is the shorter of the two is prior to the other.
- The line segment representing length of gap is prior to the line segment representing length of object.

The above rule is applied for all combinations of the line segments. On the basis of this rule, a filtering function are implemented, which makes the line segments assumed to be unnecessary less noticeable. Figure 6 shows an example of the screen of the system in the photo mode and the length display mode. The lengths of the objects are displayed as red line segments, and the lengths of the gaps are displayed as green line segments so that users can classify easily which kind of length the line segments show. In (B) in Figure 6, there are lighter line segments, so that the metric information becomes easier to be recognized.

2.3 Hardware and Software Components

The components of the Distance Information Display System are as follows. Surface Pro 4 for tablet PC, Xtion PRO LIVE for RGB-D camera, and Bluetooth mouse for external button were employed. Figure 7 shows the external appearance of the system.

System software was developed using Microsoft's Visual Studio Community 2017. Development language was C++. In addition, OpenCV library (Ver.3.2.0)(Intel Corporation, 2018) was used for line segments recognition, and Point Cloud Li-

(a):Photo Mode

(b):Length Display Mode

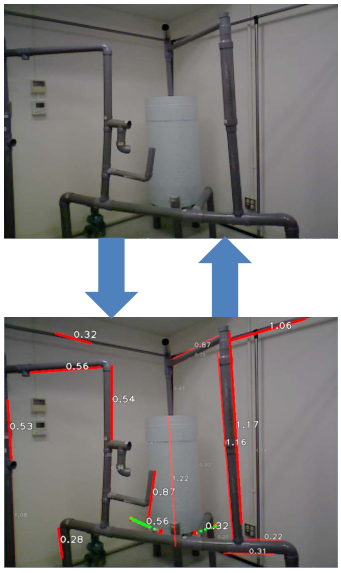

Figure 6: Screen shots of photo mode and length display mode.

Total Weight of System: 1464g

Figure 7: Appearance of the developed system.

brary (Ver.1.8.1) was used for point cloud processing(Garage, 2018).

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Figure 8: Appearance of the water purification room.

3 EVALUATION

3.1 Evaluation Purpose

The purpose of this evaluation is to confirm that the Distance Information Display System satisfies the required specifications and the purpose of the system is achieved.

3.2 Evaluation Method

On January 15, 2018, the evaluation experiment was conducted with 5 workers engaged in dismantling work at Fugen Decommissioning Engineering Center (evaluators a, b, c, d, e) as the evaluators. They tried out the Distance Information Display System in the water purification room of Fugen. Then evaluators answered the questionnaires shown in Table2, and we asked about the reason for the answers in the questionnaires. Figure 8 shows the inside of the water purification room. Table 2 shows the correspondence between questionnaire items related to the Distance Information Display System and required specifications. It was assumed that the required specification (H) is satisfied by using a contactless measurement method with a RGB-D camera, so questionnaire items about required specification (H) are not included.

The evaluator was asked to evaluate each question item shown in Table2 in five grades of ”1-do not agree”, ”2-not so likely”, ”3-neither”, ”4-slightly agree”, ”5-think so”.

3.3 Results and Discussion

The average usage time of the system was 2 minutes 32 seconds. Table 2 shows the answers of each question item.

Regarding the required specification (A) It is easy to bring the system to the site, a slightly lower evalu-

Table 2: Relationship between the required specifications and the questionnaire items, and the evaluation results.

Required specifications		Questionnaire Items	Evaluator a	b	c	d	e
(A) It is easy to bring the system to the site.	Q-1	Equipment is easy to bring into the plant.	5	5	3	3	3
(B) The system do not prevent from the work.	Q-2	Equipment does not interfere with work.	5	5	5	4	4
(C) The system do not require complicated operations.	Q-3	It is easy to orient the camera in the intended direction.	5	4	4	4	5
	Q-4	The operation of displaying the length by pressing the button can be easily understood.	5	5	5	5	5
	Q-5	The operation of displaying the length by pressing the button can be easily executed.	5	5	5	5	5
	Q-17	It is easy to use the system even when wearing gloves	5	5	5	5	5
(D) It is possible to accurately measure the intended part.	Q-8	The displayed length value seemed accurate.	3	3	3	4	3
	Q-9	How many places have you measured repeatedly since the intended length could not be measured?	1	1	3	5	2
	Q-18	You can measure the length of the intended part.	4	4	4	5	4
(E) The display is easy to see.	Q-10	You can easily understand which line length the displayed number shows.	5	4	5	4	4
	Q-11	The display of the number of the required length is not hard to see due to unnecessary length information.	4	5	5	3	2
	Q-12	You can easily understand where the line shows the length.	5	4	5	5	5
	Q-13	The display of the line of the required length is not hard to see due to unnecessary length information.	5	5	5	3	2
	Q-14	Reducing the size of the number makes it easier to see other displays.	2	2	2	3	3
	Q-15	Thinning the line makes it easier to see other displays.	2	4	3	3	3
	Q-16	By making the display of the lengths semitransparent makes other display easier to see.	2	2	3	3	3
(F) It is possible to measure in a short time.	Q-6	You do not feel stressed in the waiting time until the lengths is displayed after pressing the button.	5	4	5	5	5
	Q-7	It is effective to display multiple lengths once.	5	4	5	5	4
	Q-20	Measurement using the system is less time-consuming than measuring with tape measure.	5	5	4	5	5
(G) It is easy even for people using it for the first time to use.	Q-19	It is easy even for people handling first time to use.	5	5	5	5	5
-	Q-21	Using tools is useful for dismantling work.	4	4	5	5	4

ation was obtained at Q-1 from evaluator c, d and e. In this regard, the evaluators replied that "it is troublesome to obtain a permission to bring equipment into the plant." It is considered that because application is necessary for bringing equipments such as cameras and PCs into the NPPs from the viewpoint of confidentiality. If these system are brought into the site more frequently, application will be possibly simple or unnecessary. It is also considerd that the evaluation at Q-1 was low because the equipment of the system was a little big and thick. For the required specification "(B) The system do not prevent from the work", a high evaluation was obtained at Q-2. However, opinions that "equipment was thick, difficult to hold, bulky," were also obtained. In the future, the equipment should be smaller.

Regarding the required specification "(C) The system do not require complicated operations", a slightly higher evaluation was obtained at Q-3, and higher evaluations were obtained for each item of Q-4, Q-5, and Q-17. From this result, it can be said that the Distance Information Display System satisfies the required specification (C).

As for the required specification "(D) It is possible to accurately measure the intended part", it is low evaluation at Q-8. At Q-8, many opinions were obtained that "I do not know whether it is accurate". However, an opinion was also obtained that "obviously inappropriate length values were never displayed". Also, from Q-9, it was found that each evaluator measured the target places repeatedly. In addition, a slightly lower rating was obtained at Q-18. At Q-18, there were many opinions that the measurements were possible, but the evaluators could not measure all measuring objects once, such as "it is necessary to measure with changing viewpoint", "the desired length may not be

obtained in one measurement". In particular, there were many responses that the gap lengths could not be measured once. From these results, it was found that the Distance Information Display System does not satisfy the required specification (D) sufficiently. In the future, by improving the algorithms, the system will need to be improved so that the lengths of the gaps can be recognized more stably.

With respect to the required specification "(E)The display is easy to see", quite low evaluations were obtained with each question from Q-14 to Q-16. From this result, it turned out that the filtering process was not effective. In addition, slightly higher evaluation was obtained at Q-10 and high evaluation was obtained at Q-12, but slightly lower evaluations was obtained at Q-11 and Q-13. In particular, the evaluator e evaluated that scores at both Q-11 and Q-13 were 2. It was found that there was a possibility that filtering process disturb to recognize the desired lengths as the opinion The necessary measurement results was not noticeable due to unnecessary lengths was obtained. From these results, it can be said that the Distance Information Display System does not satisfy the required specification (E). In the future, the rules of filtering function should be improved.

Regarding the requirement "(F) It is possible to measure in a short time", high evaluations were obtained from most of the evaluators at each of the questions Q-6, Q-7, and Q-20. Therefore, it can be said that the Distance Information Display System meets the required specification (F).

Regarding the requirement "(G) It is easy even for people using it for the first time to use", all the evaluators answered 5 point. Therefore, it can be said that the Distance Information Display System meets the required specification (G).

Finally, regarding the usefulness of the Distance Information Display System in the dismantling work, three of the evaluators answered 5 point, and the others answered 4 point. From the results, it was found that the Distance Information Display System may be useful for disassembling work.

4 CONCLUSION

In this study, in order to make measuring lengths of the objects and the gaps at NPPs more efficient, the Distance Information Display System was developed, which make it easy for the dismantling workers to measure them. We asked the five evaluators to try out the system and evaluated the usefulness of the system by questionnaire and interview. The results showed that the Distance Information Display System can be used easily with extremely simple operation by the dismantling workers at NPPs, and the workers can also measure the lengths in a short time. From this result, it can be said that the system can solve the problem of manual measurement that it is troublesome to measure one by one and complicated operation can not be performed. Moreover, the measurement time can be shorter by using this system. However, it was also found that the hardware was bulky, the measurement results was difficult to see because the filtering process was not effective, and the lengths of the intended part, especially the length of the gap, could not be displayed in some cases. The future tasks are to make the hardware smaller, improve the filtering process, and develop the algorithm making the recognition the lengths of the gap more stably. In addition, we consider that why our system failed is that all length information is extracted automatically. Therefore, it is possible that fusion of automatic measurement and manual measurement is the most suitable method. Now, we try to integrate the automatic measurement and manual measurement such as a system in Figure 9. In this system, when users adjust a measurement target on center of the display manually, they can obtain the length information of the target automatically.

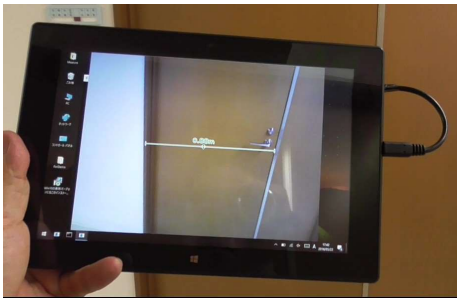

Figure 9: A System including manual and automatic measurement function.

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