Development of a Tracking Method for Augmented Reality Applied to Nuclear Plant Maintenance Work : (1) Barcode Marker

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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 are desired.

On the other hand, recent information technologies have been progressed very rapidly. Among them, state-of-the-art information technologies such as augmented reality (AR) aim at real world rather than cyberspace. Recently, AR has been developed rapidly for practical use. As mentioned above, it is expected to improve efficiency of maintenance work and reduce human errors by applying AR to support the maintenance work of NPP. The authors have developed a prototype AR system to support water system isolation task in periodic maintenance work for nuclear power plants and evaluated its information presentation devices (Shimoda, 2004).

Although AR has a great possibility to apply to various field work support, only some studies can be used in practice. One of the problems is a tracking technique, which is a key technology of AR. It is, however, difficult to introduce conventional tracking techniques such as GPS method (Thomas, 1998), ultrasonic method (Newman, 2001), magnetic sensor method (State, 1996), artificial marker method (Kato, 1999) and markerless method (Comport, 2003) into NPP fields because of the problems such as obstacles, surrounding metal objects, stability, expensive cost and narrow tracking area. In this study, therefore, the authors have improved artificial marker method, developed a long barcode marker which can be directly pasted on the pipes in plant fields, and then proposed a technique to realize fast, stable and less expensive tracking method.

2. Design of Barcode Marker and Development of Tracking Method

One of the most typical marker tracking method is ARToolKit(Kato 1999). This method employs 80mm black square with a pattern as a marker and has been used for various AR studies. ARToolKit, however, can recognize the marker only when the distance between the marker and the camera is less than 2 meter when a camera of VGA resolution is used. If it is applied to plant maintenance work which need wide area tracking, lots of markers should be pasted in the plant field. Although it is possible to extend the distance between the marker and the camera when the size of the marker is expand, it is not practical. For instance, when the distance is extended to 5 meters, it is necessary to expand the size of the marker to 400mm square for the stable tracking and it is difficult to paste such large marker in the plant field.

In this study, therefore, a long barcode type marker, which width is 40mm and length is approx. 700-1000mm, is proposed in order to extend the distance between the marker and the camera to 5 meters. In addition, the long marker can be easily pasted on the pipes, which exist all around the plant field. Figure 1 shows the image of barcode marker and the tracking system employing the marker.

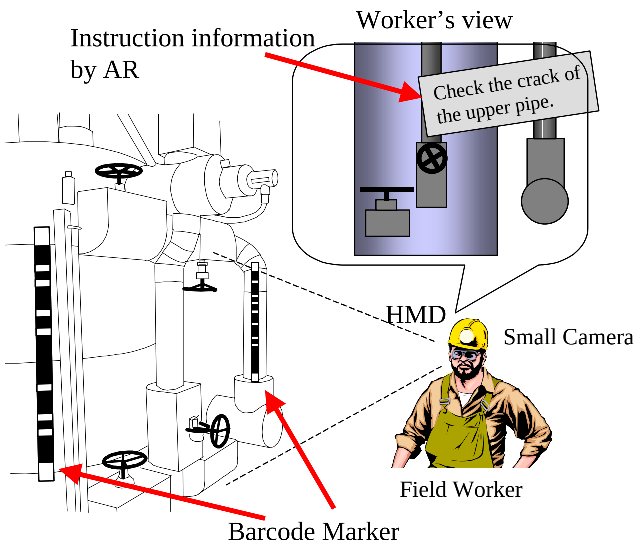


Figure 1: Image of Barcode marker and Tracking System.

2.1 Design of Barcode Marker

Figure 2 shows the example of designed barcode marker. It arranges 40mm black squares and 40mm versus 80mm black rectangles in a line with 20mm gaps. The total number of the black squares and rectangles is 11. And, the square is coded as "0", while the rectangle is "1". So that one barcode marker can express 11 bits code. 7 bits out of 11 are expressed its ID, while the rest of 4 bits are Hamming code. By using this coding method, 128 kind of barcode marker can be made with arbitrary one bit error correction.

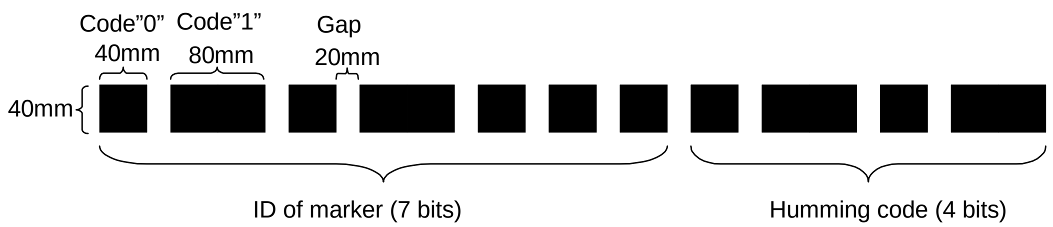


Figure 2: An Example of Barcode Marker.

2.2 Recognition of Barcode Marker

Recognition of the barcode marker is the key technology of the proposed method. The details of the recognition procedure are as follows;

(1) Binarization: Binarize the captured image with the camera at preset threshold level.

(2) Labeling: Collect the connected pixels and mark a unique label on the connected part.

(3) Narrowing search area: Exclude the parts which have no possibility as the part of the marker by its area and shape.

(4) Extraction parts of marker: Pick up the 10-12 parts which are arranged in a line as a candidate of barcode marker.

(5) Decision of code: Decide the code of barcode marker from the area of each part.

(6) Comparison with pre-registered barcode marker: Correct the code of the marker with Humming code part and compare it with pre-registered barcode marker.

It is possible to extract barcode markers from the captured image by using the above algorithm. The recognition of the barcode marker is originally conducted in order for AR tracking, however, it can be applied to automatic detection of pipe distortion by pasting it on the pipe and adding some procedure into the above algorithm.

2.3 Development of Tracking Method

The three dimensional positions of both ends of the markers should be registered in the tracking system with their IDs in advance. In order to calculate the camera position and orientation, two barcode markers are necessary in the camera image. In case that the two markers are on the same plane (coplanar), for example, both of them are pasted on the vertical pipes, the camera position and orientation can be calculated by coplanar P4P solution method using three dimensional positions of both markers. On the other hand, in case that the two markers are not on the same plane (noncoplanar), the camera position and orientation can be calculated by noncoplaner P6P solution method using three dimensional positions of both ends and center point of the markers. The decision whether the two markers are coplanar or not can be judged by the registered three-dimensional positions of the two markers.

When the camera position and orientation are calculated, virtual information can be superimposed at the designated location on the camera (or user's) view.

3. Experimental Evaluation of Marker Recognition

The evaluational points of this tracking method are recognition rate, speed and stability of the barcode marker. The authors, therefore, conducted evaluation experiment of them in their laboratory.

3.1 Experimental Method

First, the coordinate in this experiment was set that the origin as upper left corner of the camera image, X axis as right direction and Y axis as down direction. Then a barcode marker was pasted on a pipe which diameter was 60mm and length was 1100mm. The camera was fixed horizontally. The initial positions of the pipe were 0 degree(horizontal) and 90 degree(vertical) in XY plane. In the experiment, it was examined whether the marker could be recognized with various conditions of distance between the camera and the marker, and rotation angle of the marker where the rotation axis was vertical direction through the center of the pipe. Rotation angles were from 0 to 80 degrees with 20 degrees step as shown in Figure 3, while the distances were from 1 to 6 meters with 1 meter step. The lighting condition of the experimental environment was fluorescent light on the ceiling and the illumination at the pipe position was 120 lux. The background of the pipe was white plane and the threshold level of the binarization was 90 out of 256 levels (0:dark, 255:bright).

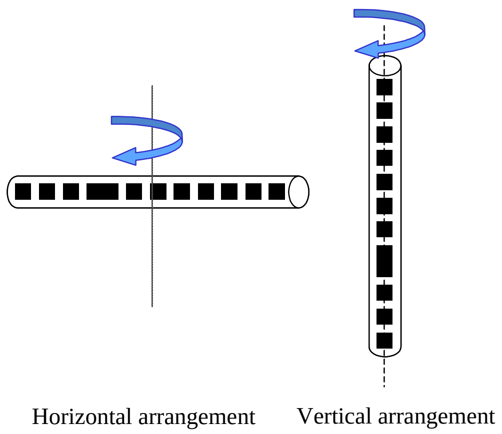


Figure 3: Rotation of Pipe.

The prototype system of the proposed tracking method was developed by Visual C++ 6.0 with Windows XP as Operating System, and the hardware was shown in Table 1.

Table 1: Specifications of Hardware Components

Component	Model	Specification	
CCD Camera	WAT-240A	Total pixels	H524 x V497
		Synchronization method	Internal
		Output signal	Video composite
		White balance	Automatic
		Exposure	Automatic
		Supply voltage	+5.4 – 7.5 V
		Size	W36.0 x H30.0 x D15.0 mm
		Weight	30 g
Laptop PC	Thinkpad X31, IBM	OS	Windows XP Professional
		CPU	Pentium Mobile 1.4GHz
		Memory	256MB
		HDD	40GB
		Size	W273 x H223 x D24.9 mm
		Weight	1.64 kg
Video Capturing System	USB-CAP2, IO-DATA	Frame size	H320 x V240
		Supply Voltage	5.0 V
		Size	W15.1 x H82 x D31 mm
		Weight	90 g

3.2 Experimental Result

Table 2 shows the experimental result.

Table 2: Experimental Result

Pipe Arrangement	Rotation Angle	Distance between marker and camera					
		1m	2m	3m	4m	5m	6m
Horizontal	0 degree	OK	OK	OK	OK	OK	OK
	20 degree	OK	OK	OK	OK	OK	-
	40 degree	OK	OK	OK	OK	-	-
	60 degree	OK	OK	-	-	-	-
	80 degree	-	OK	-	-	-	-
Vertical	0 degree	OK	OK	OK	OK	OK	OK
	20 degree	OK	OK	OK	OK	OK	OK
	40 degree	OK	OK	OK	OK	-	-
	60 degree	OK	OK	-	-	-	-
	80 degree	-	-	-	-	-	-

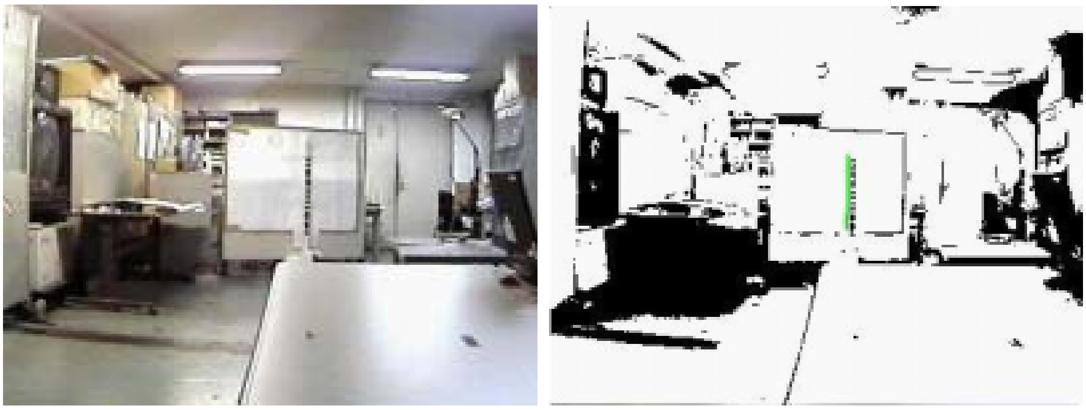
"OK" means that the marker could be recognized. "-" means that it could not be recognized.

In the experiment, the marker could be recognized from 6 meters far from the camera when the rotation angle was 0 degree as shown in Figure 4. In case that the rotation angle was within 40 degrees, it could be recognized 4 meters far from the camera, while it could not be recognized in all the distances when the rotation angle was 80 degree as shown in Figure 4.

3.3 Discussion

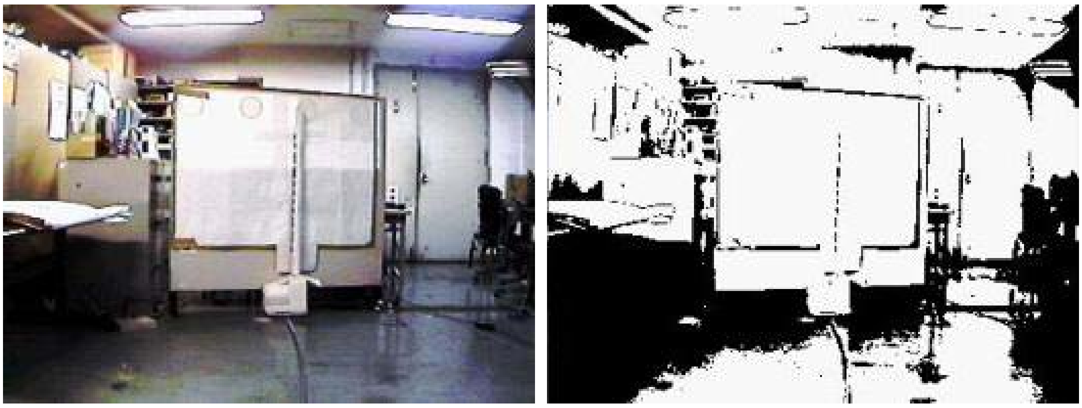
The overall recognition rate of the horizontal pipe arrangement was lower than that of vertical arrangement. In case of vertical pipe arrangement, the area of all the marker parts becomes small at the same time. On the other hand, in case of horizontal pipe arrangement, perspective difference occurs and the area of the near marker part becomes bigger than that of the far part. This causes reduction of the recognition rate of horizontal pipe rotation.

The speed of the recognition was from 10 to 30 fps(frames per second), and it was enough agreeable speed for AR tracking system.



(a)Captured image (b)Binary image

Figure 4: Marker Image (6 meters, 0 degree).



(a)Captured image (b)Binary image

Figure 5: Marker Image (4 meters, 80 degree).

4. Trial Use in Fugen NPP

The experiment mentioned above was conducted in ideal experimental environment in a laboratory, however, the actual plant field is not ideal environment such as dark lighting and arrangement of various surrounding equipment. The authors, therefore, conducted a trial use of the prototype tracking system in a water purification facility of Fugen NPP as a mockup of real NPP field. In this experiment, 10 barcode markers were pasted in 8.0 x 9.5 meter area as shown in Figure 6 and Figure 7. An experimenter walked around the area with the prototype system and measured the recognition rate of the barcode marker. All the IDs of the markers were registered in the system in advance.

Figure 8 shows an example of recognized barcode markers. In the figure, the ID numbers of the recognized markers appear near the markers when they are correctly recognized.

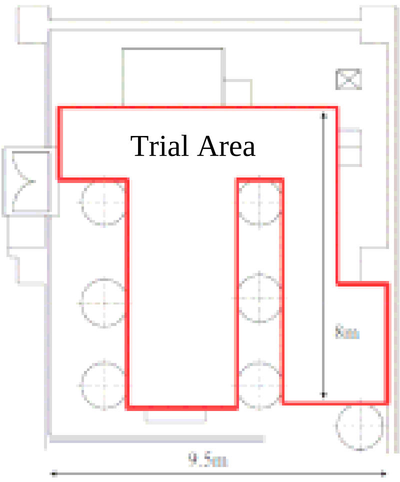


Figure 6: Trial Area. Figure 7: Examples of Pasted Barcode Markers

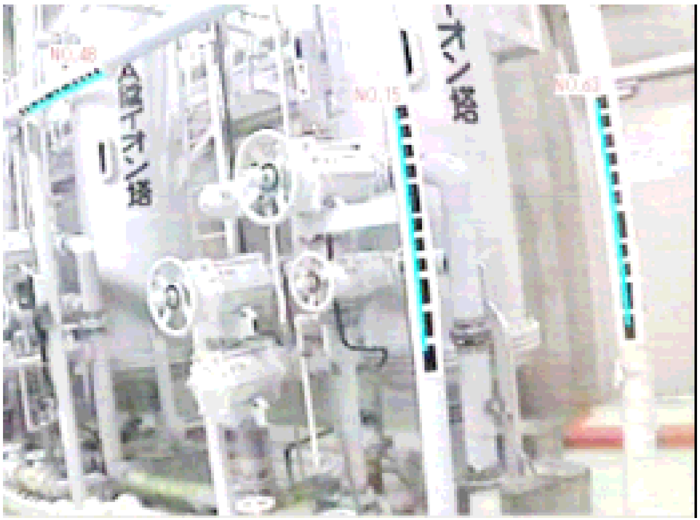


Figure 8: An Example of Marker Recognition.

As the result, recognition rate was 52.8% and erroneous recognition rate was 1.8% in 1,000 frame images in which al least one marker was captured. The cases when the markers could not be recognized are mainly as follows;

(1) In case that a marker image was captured against the light (backlight situation)as shown in Figure 9,
(2) In case that a marker was far from the camera and
(3) In case that the angle of a marker against the camera direction was large.

When the marker image was captured enough large and clear, the marker could be recognized without erroneous recognition. It can be said that the recognition rate is enough agreeable for practical use, if the locations of the markers are appropriately arranged.

Figure 10 shows an example of the proposed tracking method for an inspection support of inside of the pipe. In the figure, an inspection location is indicated on the pipe and the inspection result by Electro-magnetic Acoustic Transducer (EMAT) is displayed in left bottom corner. In this example, it is assumed that EMAT inspection was conducted in advance. A field worker or a maintenance work director can easily recognize the inspection location and its result in the maintenance work.

Figure 9: A Case When a Marker Image was Captured against Light.

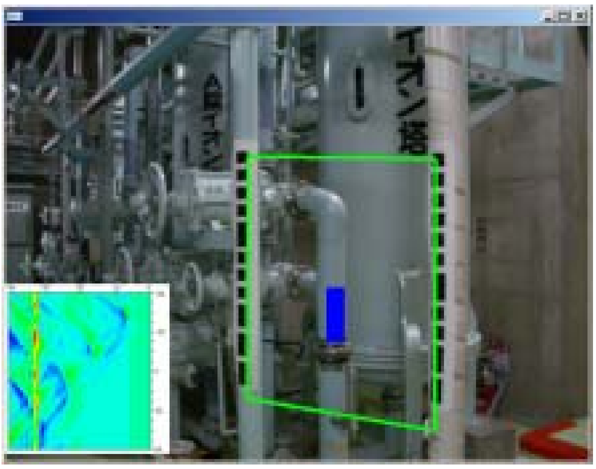


Figure 10: An Example of Inspection Support with Proposed Tracking Method

5. Conclusion

In this study, the authors proposed a tracking method of augmented reality for NPP maintenance work support and evaluate it in a laboratory experiment and trial use in Fugen plant. It employs long barcode-type markers, which can be easily pasted on the pipes in NPP in order to track the position and orientation of the camera attached on the user. A prototype system of the proposed method was developed and an experiment was conducted to evaluate the recognition rate and speed in a laboratory. In addition, the authors tried to use the prototype system in the water purification facility in Fugen NPP. As the result, it was found that the marker recognition method was feasible and it could be applied to actual plant field if the markers were pasted at appropriate locations. The proposed tracking method, however, needs to take pictures in which al least two barcode markers are captured in order to calculate the camera position and orientation.

In the future, the authors plan to improve the tracking system, such as multi-camera to expand camera view, improvement of camera resolution and improvement of recognition algorithm. Then the authors will develop a maintenance support system and a radiation visualization system as examples of the proposed tracking method.

Acknowledgement

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