Development of a Tracking Method for Augmented Reality Applied to Nuclear Plant Maintenance Work

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Abstract

In this paper, a plant maintenance support method is described, which employs the state-of-the-art information technology, Augmented Reality (AR), in order to improve efficiency of NPP maintenance work and to prevent from human error. Although AR has a great possibility to support various works in real world, it is difficult to apply it to actual work support because the tracking method is the bottleneck for the practical use. In this study, a barcode marker tracking method is proposed to apply AR system for a maintenance work support in NPP field. The proposed method calculates the users position and orientation in real time by two long markers, which are captured by the user-mounted camera. The markers can be easily pasted on the pipes in plant field, and they can be easily recognized in long distance in order to reduce the number of pasted markers in the work field. Experiments were conducted in a laboratory and plant field to evaluate the proposed method. The results show that (1)fast and stable tracking can be realized, (2)position error in camera view is less than 1%, which is almost perfect under the limitation of camera resolution, and (3)it is relatively difficult to catch two markers in one camera view especially in short distance.

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 the 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.

At the same time, recent information technologies have been developed rapidly. One of the state-of-the-art information technologies, Augmented Reality (AR) aims at real world rather than virtual world. Recently AR becomes practical and applied in many different areas. As mentioned above, it is expected to develop a NPP-maintenance supporting AR system to improve efficiency of the maintenance work and reduce the human errors. The authors have developed a prototype AR supporting system in maintenance work for the water system isolation task in periodical maintenance work [1].

Although AR has a great possibility to apply to various field work support, only some studies can be used in practice. AR technology has some limitations to be applied practically in many field works in NPP maintenance. One of them is tracking method, which is a key technology of AR. It is, however, difficult to introduce conventional tracking techniques such as GPS method [2], ultrasonic method [3], magnetic field method [4], marker method[5] and markerless method[6] into NPP fields directly because of the problems such as obstacles, surrounding metal objects, expensive cost and narrow tracking area. In this study, therefore, the authors have improved marker method, developed a long and narrow 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 Type Marker and Development of Tracking Method

Artificial marker method (typically ARToolKit) 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 1 meter. If it is applied to plant maintenance work which needs 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 expanded, 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 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.

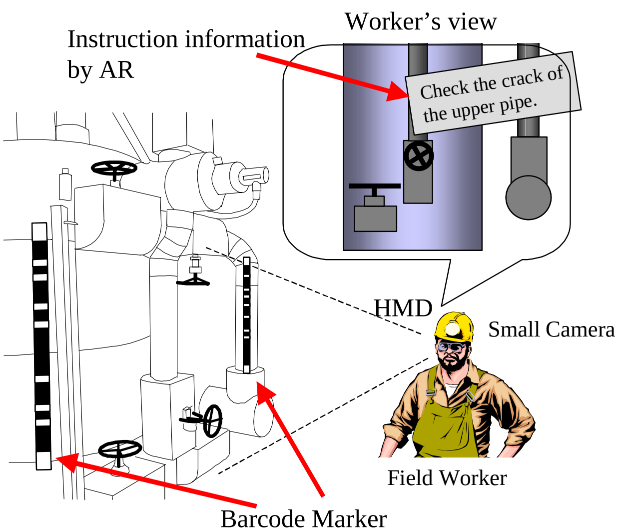


Figure 1: Image of Barcode marker and Tracking System.

2.1. Design of Barcode Marker

Figure 2 shows an 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". One barcode marker, therefore, can express 11 bits code. 7 bits out of 11 expresses 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.

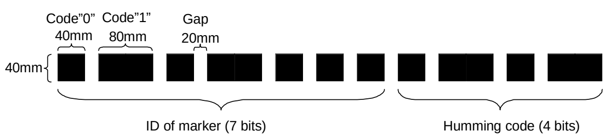


Figure 2: An Example of Barcode Marker.

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 also 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 barcode marker can be recognized very easily in longer distance, so that the number of markers which should be pasted in the environment can be reduced. It is, however, impossible to calculate the camera position and orientation by only one marker because all the recognition points are in a line. At least two markers, therefore, are necessary to calculate the camera position and orientation. The proposed method employs P4P solution method which has been improved from ARToolkit, so that the two markers should be placed in the same direction such as all located in vertical. The new P4P solution method can adapt to large view angle condition such as in the NPP field. Figure 3 shows the concept of P4P solution method. The distance of two markers is treated as the side length of the virtual square and one of the marker ends as the vertex of the square. Other three vertexes are calculated by linear fitting from the pre-registered three-dimensional position. With this virtual square and P4P solution method, the 3D position and angle of the camera can be calculated.

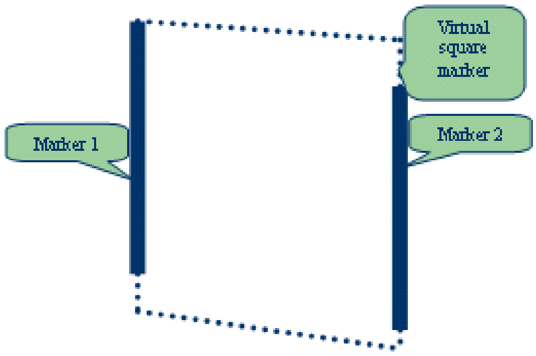
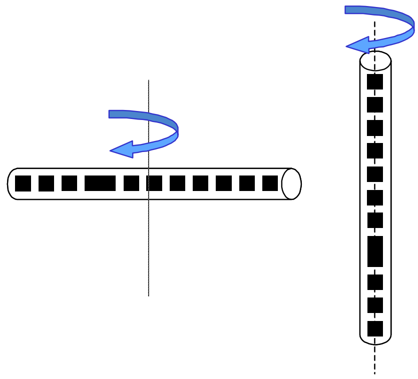


Figure 3: Virtual Square made by Two Markers



Horizontal arrangement Vertical arrangement

Figure 4: Rotation of Pipe.

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 4, 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).

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

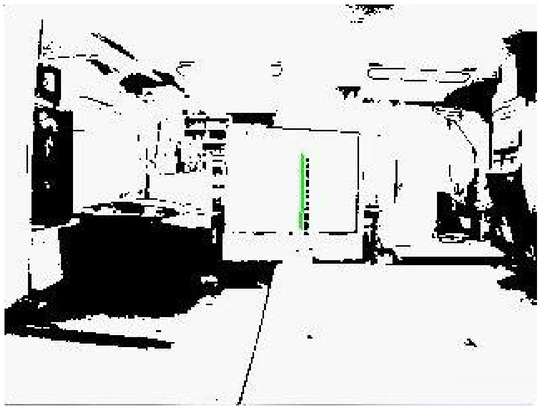
Table 2 shows the experimental result. In the experiment, the marker could be recognized from 6 meters far from the camera when the rotation angle was 0 degree as shown in Figure 5. In case that the rotation angle was within 40 degrees, it could be recognized 4 meters far from the camera, while it could not be recognized in all the distances when the rotation angle was 80 degree.

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.

(a) Captured Image



(b) Binary Image

Figure 5: Marker Image (6 meters, 0 degree).

Figure 6 shows the recognition area which is mapped from the experimental result as shown in Table 2. The area means that the barcode marker can be recognized when the camera is located in the area.

As the result of the recognition speed, it was more than 30 fps using the prototype system and it is enough fast to satisfy to be used as an augmented reality system for the NPP maintenance work support.

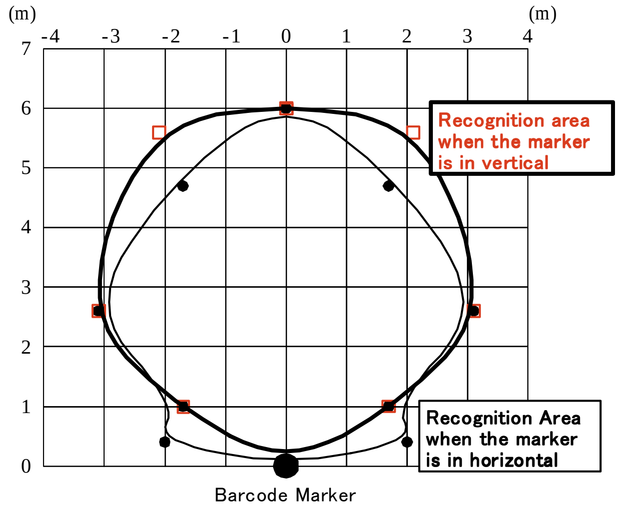


Figure 6: Recognition Area of Camera.

4. Trial Use in Plant Environment

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 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 7. An experimenter walked around the area with the prototype system and measured the recognition rate of the barcode marker. All the IDs 3D positionsof the markers were registered in the system in advance. The illumination in the trial use is 300 lux in the horizontal plane and 100-150 lux on the marker position.

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.

The recognition rate was 65.8% in all the 1000 frames; however it rises 99.5% in the frames in which the barcode marker was captured clearly. 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),
(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.

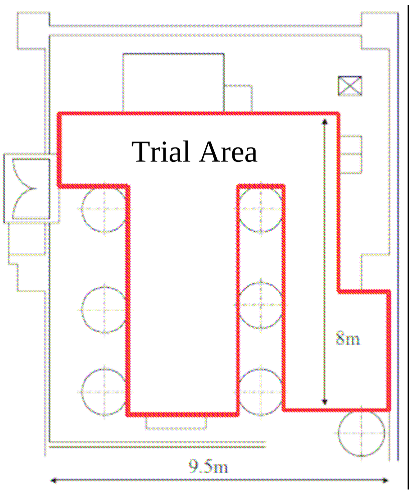


Figure 7: Trial Area

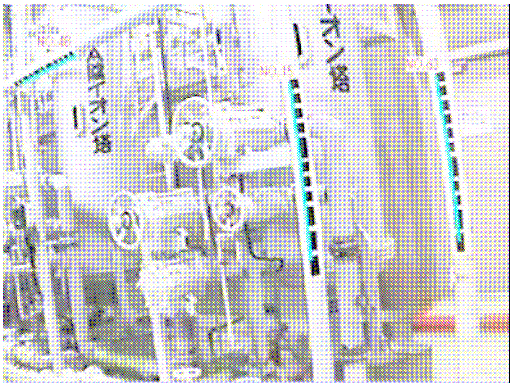


Figure 8: An Example of Marker Recognition.

The virtual square recognition rate (when two or more barcode markers are captured) is up to 99.5%. The rate of position error less than 3 pixels is 87.2% (5 pixels: 93.2%) in captured image plane when two markers are recognized in the same image.

The result of the trial use shows: (1) fast and stable tracking is realized; (2) most of position error in camera view is less than 1%, which is agreeable under the limitation of camera resolution; (3) the barcode markers are large and it is relatively difficult to catch two markers in one camera view especially in short distance.

5. Conclusion

In this study, the authors proposed a barcode marker tracking method of augmented reality for maintenance support work of NPP and evaluated it by experiments. It employs long barcode 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 a laboratory experiment was conducted to evaluate the recognition rate and speed. In addition, the authors tried to use the prototype system in the water purification facility as a mockup of real plant environment. 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 result also shows the system can track camera position and pose stably and accurately. The proposed tracking method, however, needs to take pictures in which at 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 example applications of the proposed tracking method.

Acknowledgement

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