Development of AR Tracking Method for NPP Maintenance Work Support

Z. Bian, T. Nakai, M. Maeshima,
H. Shimoda, H. Ishii, H. Yoshikawa
Graduate School of Energy Science, Kyoto University. Gakasho Uji Kyoto Japan
{bianzq, nakai, maeshima, shimoda, hirotake, yosikawa}@uji.energy.kyoto-u.ac.jp

Abstract: Nuclear power plant (NPP) need to be maintained periodically. Improvement of maintenance work efficiency and reduction of its cost at the same time is desired. One of the state-of-the-art information technologies, Augmented Reality (AR) aims at real world rather than virtual world. Although augmented reality (AR) has a great possibility to support various works such as a maintenance work in nuclear power plants (NPPs), 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 employs long and narrow markers which can be 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 plant field. The evaluation experiment was conducted in a laboratory and plant field. The results show that (1) fast and stable tracking can be realized; (2) position error in camera view is less than 1%, which is perfect 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.
Keywords: Augmented Reality, Nuclear Power Plant, Maintenance, Barcode Marker, Tracking Method.

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 [6] such as GPS method [3], ultrasonic method [4], magnetic field method [5], marker method and markerless method 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. Development of Barcode Marker

One of the most typical marker tracking methods is ARToolKit (by HIT Lab in Washington University). 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 1 meter. 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 markers and the camera when the size of markers expands, 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 500mm 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.

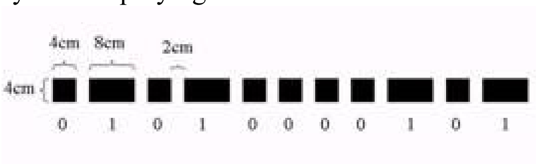

Figure 1 Concept Image of Barcode Marker.

2.1 Design of Barcode Marker

Figure 1 shows the concept image of the barcode marker. The barcode marker is a combination of black elements. One barcode marker has 11 bits and the length of 4cm means "0", while that of 8cm means "1". 7 out of 11 bits indicate the ID of the marker and the rest of 4 bits are used for error detection and correction information as humming code. Therefore the length of the barcode marker can be from 640mm to 1080mm, which is easy to find the pasted place in NPP field. On the other hand, a small video camera worn on the user takes pictures of the barcode markers, and it recognizes the barcode IDs and their location. The image is binarized to black and white for fast and stable recognition of markers. In order that the black and white barcode marker can be recognized even in the serious light condition, double threshold levels are employed in the image binarization process and achieve stable recognition. Figure 2 shows the concrete image of the barcode marker tracking method.

2.2 Recognition of Barcode Marker

The marker recognition procedure is as follows:

(1) Take one picture of barcode marker;

(2) Binarization: Binarize the captured image with current threshold level;

(3) Labeling: Collect the connected pixels and mark a unique label on the connected part;

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

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

(6) Decision of code: Decide the code of barcode marker from the area of each part;

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

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 3 vertexes are calculated by linear fitting from the pre-registered three-dimensional position. With this virtual square and P4P solution method, the 3-D position and angle of the camera can be calculated.

3. Evaluation Experiment

A laboratory experiment was conducted in order to evaluate the proposed barcode marker tracking method. The evaluation points are recognition rate, speed, stability and accuracy.

3.1 Experimental Method

A prototype system of the proposed tracking method has been developed, and used in the experiment system. It was developed by

Visual C++ 6.0 with Windows XP as operation system and the hardware shown in Table 1.

Figure 4 shows the experiment condition. Two barcode markers are pasted on a white board and rotate from 0 deg to 80 deg by 20 degree step. The distance from the markers to camera changes from 2 meter to 6 meter by 1 meter step. The illumination in the experiment condition is 100~120 lux.

Table 1 Specification 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 1.6GHz
		Memory	512MB
		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

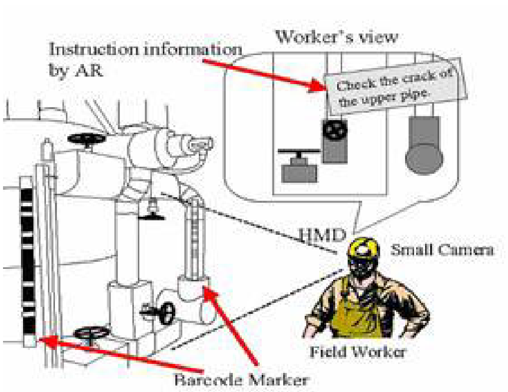

Figure 2 Concept Image of Proposed Tracking Method.

Table 2 Experiment Result (unit pixel): The Relationship of Error and Angle, Distance (X means no recognition)

Angle/Distance(m)	2.0	3.0	4.0	5.0	6.0
0	2.1	1.2	0.7	0.5	0.5
20	1.4	1.1	1.1	1.2	0.8
40	3.1	1.2	0.9	1	0.8
60	X	23.1	1.5	X	X
80	X	25.1	X	X	X

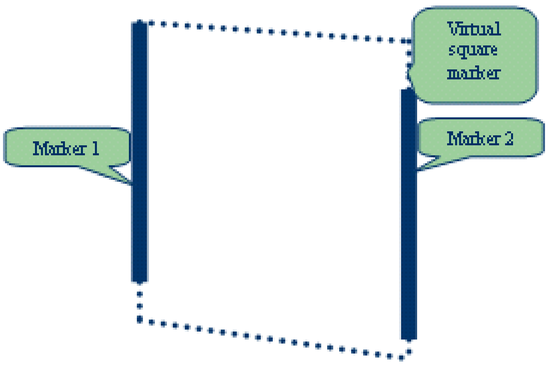

Figure 3 Square Marker Making Method

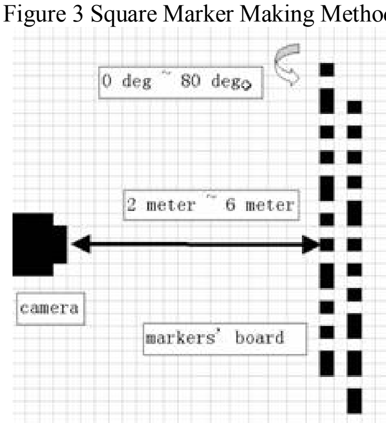

Figure 4 Experiment Condition

Figure 5 Recognition Image of 2 meter, 40 deg

Figure 6 Recognition Image of 4 meter, 60 deg

3.2 Experimental Result

The positional error is defined in the image plane (superimposed screen), which is calculated as follows:

$$err = \sqrt{\sum_{i=1}^{4}[(x_{ci}-x_{ri})^2+(y_{ci}-y_{ri})^2]} \Big/ 4 \qquad (1)$$

In equation (1), (x_{ci},y_{ci}) is screen coordinate calculated from global 3-d position by multiplying the transformation matrix, which is calculated in the tracking procedure. (x_{ri} , y_{ni}) is the real screen coordinate. The four points is set to the four vertexes of the virtual square marker. The positional error is the standard error in the calculated four vertexes position in image plane from the captured four vertexes position.

The experiment result is shown in Table 2. It shows that the markers can be recognized successfully and position error is smaller than 1% (less than 3 pixels when camera resolution is 320*240) when the view angle is less than 40deg under the condition from 2meter to 6meter. In case of larger angle, the error becomes large even if the marker is correctly recognized. Figure 5 and 6 shows two of the successful recognition images.

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.

3.3 Discussion

The experimental result shows the recognition and tracking can work enough speedily and stably. The superimpose position accuracy is high enough for further application in NPP plant field work. Furthermore, there are some methods for improving the recognition rate, angle and distance, such as widening the width of the barcode markers and pasting on round pipes.

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 dark lighting and arranged 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 trial use, 7 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 of the markers were registered in the system in advance. The illumination in the trial use is 300 lux in the horisonal plane and 100~150 lux on the marker position.

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

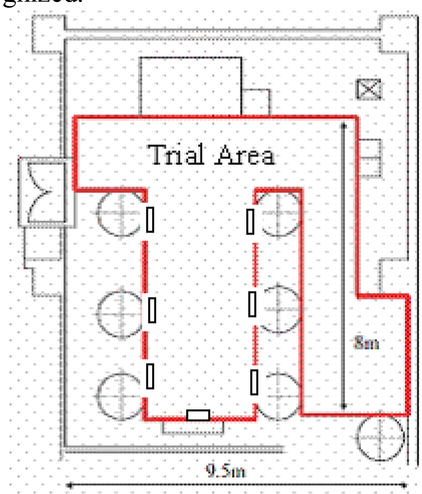

Figure 7: Trial Area

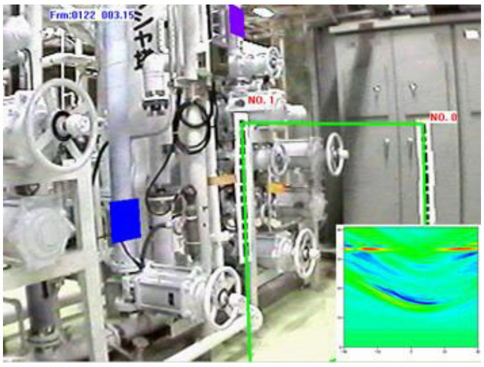

Fig. 8 Recognized virtual square marker

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.
(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.

The virtual marker 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%) 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 in a laboratory experiment and a trial use in Fugen plant. 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 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. Experiment 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.

References

[1] Comport, A.I., Marchand, É., Chaumette, F., (2003), A Real-Time Tracker for Markerless Augmented Reality, Proc. of ISMAR2003, pp.36-45.

[2] Kato, H., Billinghurst, M. (1999). Marker Tracking and HMD Calibration for a Video-based Augmented Reality Conferencing System, Proc. of 2nd Int. Workshop on Augmented Reality, pp.85-94.

[3] Newman, J., Ingram, D., Hopper, A., Augmented Reality in a Wide Area Sentient Environment, Proc. of ISAR2001, pp.77-86.

[4] Shimoda,H., Ishii,H., Yamazaki,Y. Wu,W., Yoshikawa,H. (2004), A Support System for Water System Isolation Task in NPP by Using Augmented Reality and RFID , Prof. of The 6th International Conference on Nuclear Thermal Hydraulics, Operations and Safety (NUTHOS-6), N6P205.

[5] State,A., Hirota,G., Chen, D.T., Garrett,W.F., Livingston,M.A., (1996), Superior augmented reality registration by integrating landmark tracking and magnetic tracking, Proc, of SIGGRAPH 96, pp.429-438. ACM.

[6] Thomas,B., Demczuk,V., Piekarski,W., Hepworth,D., Gunther,B. (1998), A Wearable Computer System with Augmented Reality to Support Terrestrial Navigation, 2ND. International Symposium on Wearable Computers, pp.166-167.