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.

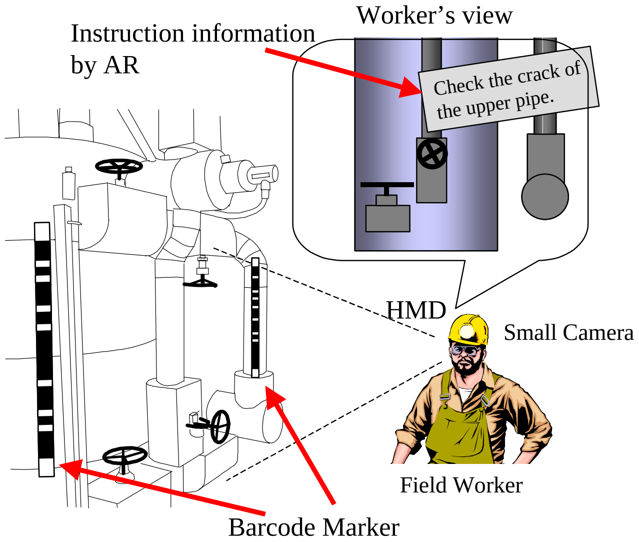


Figure 1: Image of Barcode marker and Tracking System.

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.

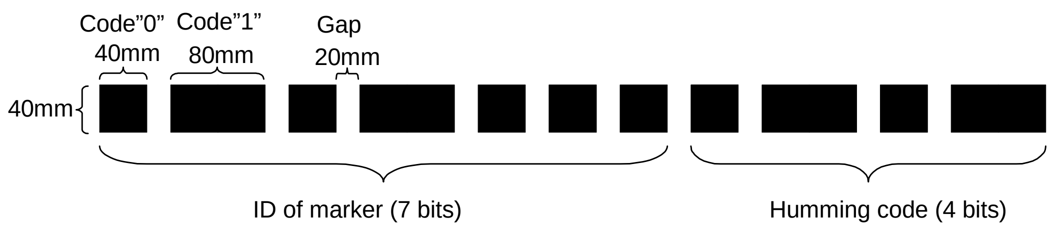


Figure 2: An Example of Barcode Marker.

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).

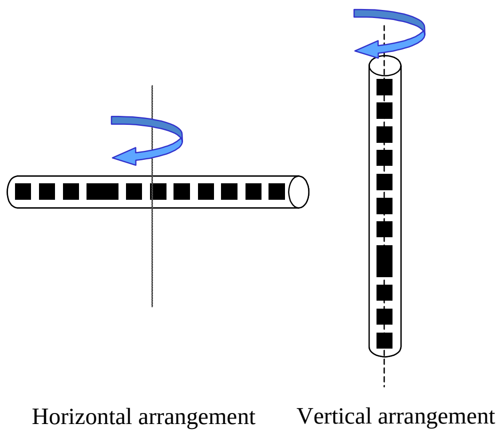


Figure 3: Rotation of Pipe.

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	-	-	-	-	-	-

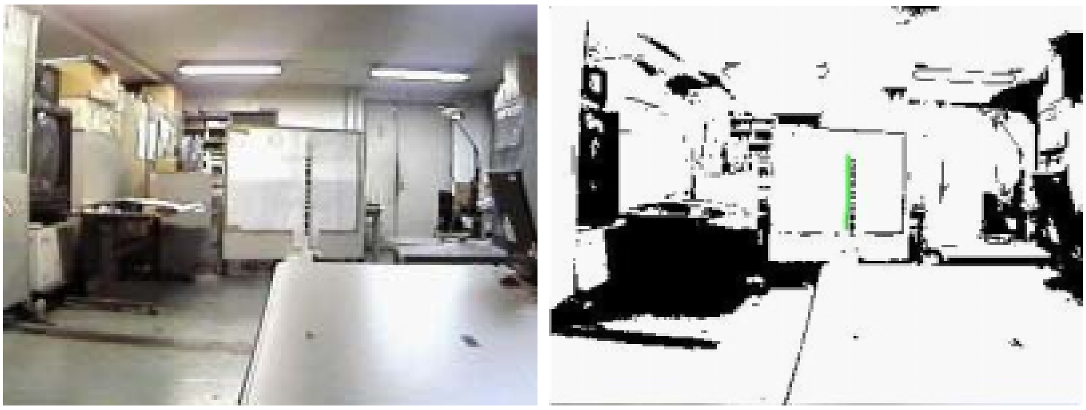
"OK" means that the marker could be recognized. "-" means that it could not be recognized.

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

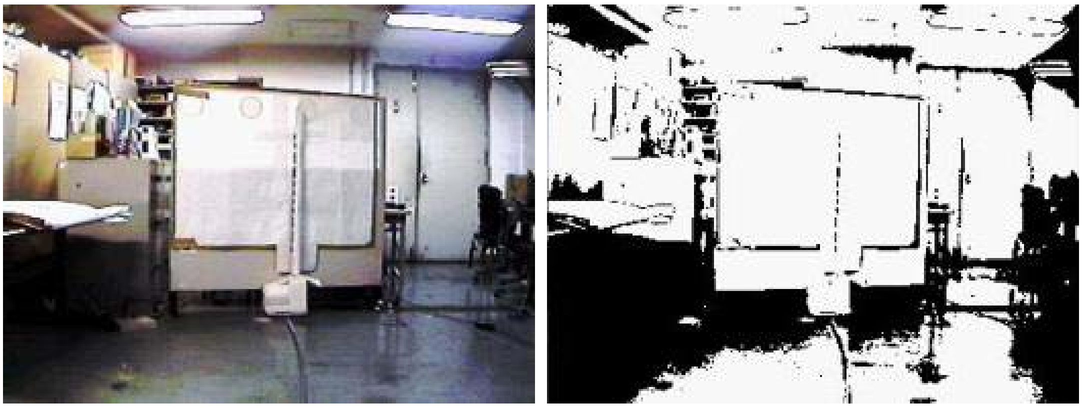
The overall recognition rate of the horizontal pipe arrangement was lower than that of vertical arrangement. In case of vertical pipe arrangement, the area of all the marker parts becomes small at the same time. On the other hand, in case of horizontal pipe arrangement, perspective difference occurs 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.

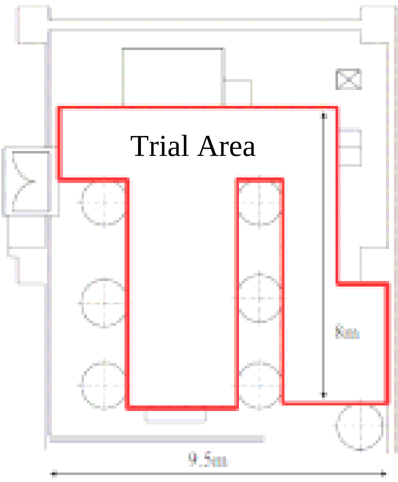


Figure 6: Trial Area.   Figure 7: Examples of Pasted Barcode Markers

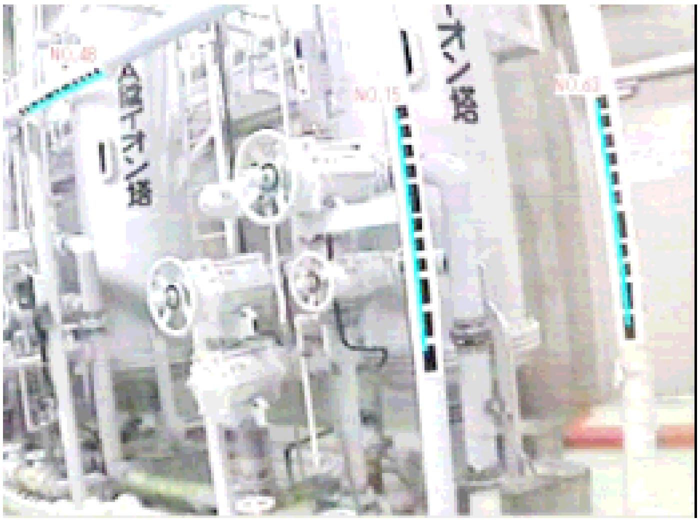


Figure 8: An Example of Marker Recognition.

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.

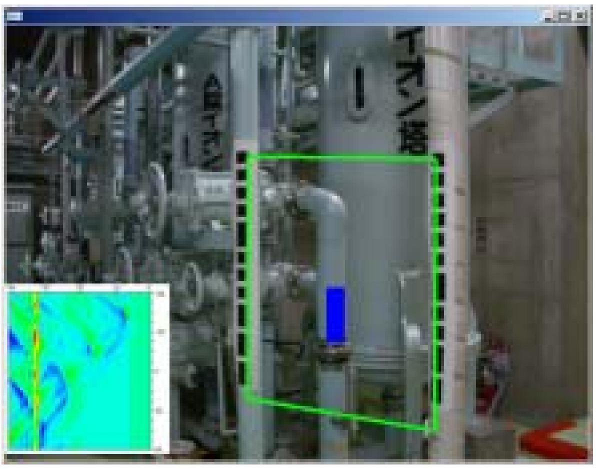


Figure 10: An Example of Inspection Support with Proposed Tracking Method

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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Development of a Tracking Method for Augmented Reality
Applied to Nuclear Plant Maintenance Work : (2) Circular Marker

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1. Introduction

In order to stabilize energy supply, it is necessary not only to improve power generation system as machines itself, but also to improve its human machine interface. Especially, in the field of maintenance work of nuclear power plants (NPPs), there are some rooms to improve its efficiency and safety by introducing state-of-the-art information technology[1]. Augmented Reality (AR) is one of the promising technologies that will be able to improve efficiency of the maintenance work and reduce human errors. The AR expands the surrounding real world by superimposing computer-generated information on user's view and represents various information more intuitively than with legacy interfaces such as paper-based instruction documents[2].

In order to apply the AR to the maintenance work, a tracking method that measures position and rotation of workers in real time is indispensable. Until now, many kinds of tracking methods have been developed and applied to many applications[3][4], but it is difficult to introduce these conventional tracking methods into NPP maintenance because these methods does not fulfill all requirements from the viewpoint of accuracy, stability and availability when used in NPP. In this study, therefore, a new circular marker has been designed and a tracking system that recognizes plural circular markers at one time and uses them for calculating the position and rotation of the target with high accuracy has been developed. And some experiments have been conducted in order to evaluate the accuracy and reliability of the proposed method.

The remains of this paper consist of tracking methods for AR applications, design of circular marker, recognition of circular marker and calculation of position and rotation of camera, experiments for the evaluation of developed tracking method and conclusion.

2. Tracking Methods for AR Applications : Its Strengths and Weaknesses

In order to superimpose computer-generated information on user's view at correct position, it is necessary to measure position and rotation of the user's view in real time. This technique is called "tracking" in the AR field. Until now, many kinds of tracking methods have been developed and applied to many applications. Those are the methods that employ vision sensors[5][6], ultrasonic sensors[7], magnetic sensors[8], inertial sensors[9] and so on. All of these methods have both of strengths and weaknesses.

2.1. Tracking method employing vision sensors.

Tracking method employing vision sensors is a method with which the surrounding view is captured by video camera(s) and relative position of the camera(s) against the working environment is calculated. There are two kinds of tracking method employing vision sensors. One is an artificial marker method with which artificial fiducial markers are pasted in the environment and the position and rotation of the markers (then, the position and rotation of the camera relative to the working environment) are recognized by image processing. The other is a natural feature method with which natural features such as lines and corners that exist in the working environment are extracted and their position and rotation are recognized. The artificial marker method is rather accurate and stable and is applied to several applications. But, the existing tracking method using artificial markers can recognize the marker only when the distance between the marker and the camera is very short. A huge number of the artificial markers, therefore, need to be pasted and their position and rotation need to be measured in advance, if the tracking area is need to be wide. The natural feature method is more convenient for users because it is not necessary to paste markers in advance. With the current technology, however, its accuracy and stability is rather low and its computational load is too high for the real time applications.

2.2. Tracking method employing ultrasonic sensors.

Although tracking method employing ultrasonic sensors is accurate and stable, it is necessary to place ultrasonic sensors or sources in the working environment in advance. This is a fatal weakness for use in a severe environment such as NPP. The range covered by one ultrasonic sensor is not so long that a lot of ultrasonic sensors need to be placed in order to cover wide area. Since the ultrasonic sensors are relatively expensive, it is not cost effective to use it in large environment. Moreover, there is a problem that the accuracy cannot be kept in complicated environment because of diffuse reflection of ultrasonic.

2.3. Tracking method employing magnetic sensors.

Tracking method employing magnetic sensors/transmitters is applied also in the field of virtual reality because its accuracy and stability is good in well-controlled environment. Magnetic sensors are, however, easily affected by metal obstacles and a range covered by one magnetic transmitters is short. The magnetic transmitters need to be placed in the working environment in advance.

2.4. Tracking method employing inertial sensors.

There are two kinds of inertial sensors that can be applied for the tracking. One is an acceleration sensor and the other is a gyro sensor. In both sensors, since it is not necessary to place anything in the working environment in advance, it is very convenient for users. However drift error cannot be avoided and the accuracy will decrease with time passed because of error accumulation. Moreover, with the inertial sensors, only the relative values can be obtained against its initial position and rotation. The other method, therefore, needs to be applied in order to obtain the initial position and rotation of the inertial sensors.

2.5. Basic strategy for developing a tracking method which can be used in NPP

As mentioned above, all of the existing tracking methods have weakness and cannot be introduced into NPP. A tracking method used in NPP must fulfill the following conditions;

1. It can be used inside a building.
2. Accuracy and stability should be enough to overlay the information on worker’s view at correct position.
3. It is not affected by environmental noise such as metallic obstacles, magnetic source and so on.
4. It is not necessary to locate large and/or expensive apparatus in the working environment.

Among the existing tracking method, only the tracking method employing vision sensor meets the above 4 conditions. But as mentioned before, the existing tracking method using artificial markers requires that the distance between the markers and the camera is short. In this study, therefore, we decided to try making the available distance between the markers and the camera much longer.

The basic idea is to apply circular markers instead of square markers. The square markers are used in many existing marker-based tracking methods and the position and rotation of a camera can be calculated by using 4 edges from single marker. This is a strength for use in the working environment because wide area tracking can be realized with a small number of markers. But the calculation of the position and rotation of the camera is easily affected by jaggy-shaped edges that will appear when the distance between the marker and the camera is long. Therefore, large size markers need to be used if the distance between the markers and the camera is long.

On the other hand, the calculation of the center of the circular marker is not affected by jaggy edge. This means that even if the distance between the circular marker and the camera is very long, the center of the marker can be calculated accurately. And, if each circular marker can be distinguished and the 3 dimensional position of the circular marker in the working environment is known in advance, the position and rotation of the camera can be calculated by using triangulation method.

Based on the above consideration, we decided the basic strategy of this study like follows;

1. Circular markers are applied instead of square markers.
2. The kind (ID) of the marker is distinguished by barcode-like fans located inside the circle.
3. The circular marker is designed as simple as possible in order to make it possible to distinguish the kind of the marker even if the distance between the marker and the camera is long.

But it is difficult to calculate the position and rotation of the camera from single circular marker. So we also decided that

4. The position and rotation of the camera is calculated from plural markers by using triangulation method.

A requirement that plural markers need to be captured at one time (in one frame) may be a weakness from a viewpoint of workload to setup the working environment because more markers need to be pasted than the case of square markers. But it also leads an important advantage about the accuracy of the calculation. The accuracy of the calculation depends on the distance between the feature points or lines used for the calculation. In the case of the square marker, 4 edge lines are used to calculate the position and rotation of the camera and the distance between the 4 edge lines are limited to the size of the square marker. Therefore in order to increase the accuracy of the calculation, it is necessary to enlarge the size of markers. On the other hand, in the case of the circular marker, plural markers can be used for the calculation which are distributed all over the working environment, so the distance between the features used for the calculation can be extended to the distance between the each marker.

3. Design of Circular marker

Figure 1 shows the example of the circular markers proposed in this study. The circular marker consists of one black outer circle, one white center circle and middle circle which consists several black or white fans that represent binary code by its color. The outer black circle and the center white circle are used for determining the threshold to analyze the binary code and the number of distinguishable markers varies depending on the number of the fans. If the middle circle is divided into 9 fans, 56 markers can be used at one time. And if the middle circle is divided into 11 fans, 188 markers can be used at one time (The right marker and the middle marker in Figure 1 are treated as a same marker). The number of the fans should be decided based on the purpose and environmental condition such as light and distance because too much division of the middle circle will cause a miss-recognition of the binary code. As described later, the recommended number of the division is 10 (99 markers can be used at one time).

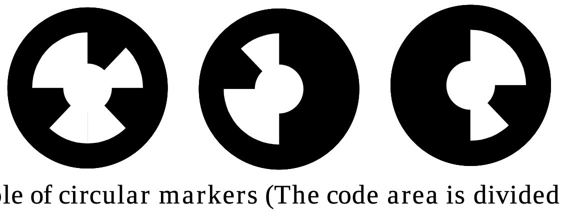

Figure 1: Example of circular markers (The code area is divided into 8 elements)

4. Recognition of Circular Marker and Calculation of Position and Rotation of Camera

A process for recognizing the circular markers can be divided into 3 steps.

(1) Ellipse Recognition Process : Extract candidates of circular markers from captured image and recognize ellipses.

(2) Marker Recognition Process : Analyze binary code of middle circle and recognize ID of markers.

(3) Tracking Process : Calculate position and rotation of the camera from plural circular markers.

The details of each process are described below.

4.1 Ellipse Recognition Process

The procedure to extract candidates of markers and recognize ellipses is as follows;

(1) Capture a gray scale image with a camera (with color conversion if necessary) and take logarithm of each pixel of the captured image.

(2) Apply 3x3 Sobel edge detector and binarize the result with single threshold.

(3) Labeling the binarized image by collecting the connected pixels and mark a unique label. Eliminate candidates which area is too small or large.

(4) Trace edges of each labeled area and calculate center of mass of each group of edges. The center of mass is assumed to be a center of ellipse.

(5) Calculate 150 ellipses that through 3 edges which are selected randomly.

(6) Calculate an ellipse by averaging the result of step (5).

(7) Calculate a sum of square distance between the calculated ellipse and the each edge point. Eliminate candidate which distance is larger than a threshold.

(8) Calculate a ratio of major axis vs. minor axis of the calculated ellipse. Eliminate candidate which ratio is larger than a threshold.

The important feature of the above algorithm is that it is not necessary to adjust the thresholds even if the light condition of the captured image is changed.

4.2 Marker Recognition Process

The procedure to analyze binary code of the middle circle and recognize IDs of the markers is as follows;

(1) Normalize the ellipses recognized in the Ellipse Recognition Process to a circle using the ratio of major axis vs. minor axis of the ellipse as shown in Figure 2.

(2) Calculate variance and average of brightness of white center circle and black outer circle. Eliminate candidate which variance is larger than a threshold. Calculate a threshold to analyze the binary code from the average of the brightness of the white center circle and black outer circle.

(3) Count pixels which brightness is larger than the threshold calculated in step (2) for each fan of middle circle. The fan which number of the counted pixels is larger than a threshold is assumed as 0 and the fan which number of the counted pixels are smaller than a threshold is assumed as 1.

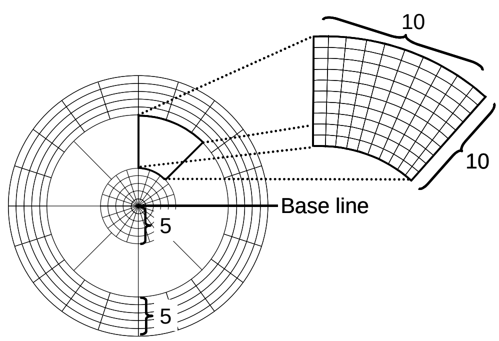

Figure 2: Normalize of circular marker (The code area is divided into 8 fans).

4.3 Tracking Process

In this study, the position and rotation of the camera is calculated by using plural markers. The method to calculate the position and rotation of the camera from plural points which 3 dimensional positions are known is categorized into a PnP (Perspective n-Point) problem. If only 3 points are available, there are a maximum of eight possible solutions, of which only four occur in real 3D space in front of the camera. If 4 points are available and these are coplanar, there is a unique solution; otherwise for non-coplanar points there are two solutions. If more than 6 points are available and they are not aligned as single line, there is a unique solution. Unfortunately, it is difficult to capture more than 6 markers at one time in the working environment. So we introduced a new method to calculate the position and rotation of the camera by using both of the solutions from PnP solver and the rough information of each circular marker's rotation. By using this method, it is possible to calculate the position and rotation of the camera only from 3 markers. The details of the method are as follows;

(1) Calculate the position and rotation of each marker relative to the camera from the size and shape of the marker on the captured image.

(2) Calculate the position and rotation of the camera from 3 markers with PnP solver. Maximum 4 solutions are obtained.

(3) Compare the result of step (1) to the result of step (2). One of the result of step (2) which is most similar to the result of step (1) is adopted.

(4) Calculate the 2 dimensional positions of all circle markers recognized in the Marker Recognition Process on the captured image by using the result of step (3).

(5) The result of step (3) is optimized by making the difference between the result of step (4) and the result of the Ellipse Recognition Process minimum.

When the position and rotation of the camera are calculated, virtual information can be superimposed at the designated location on the user's view.

5. Experiments for the Evaluation of Developed Tracking Method

Two kinds of experiments have been conducted to evaluate the accuracy and stability of the proposed method. One is for evaluating the accuracy and stability of the recognition in the case that only single marker is used. The other is for evaluating the accuracy and stability of the tracking when plural markers are used.

5.1 Developed system

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

5.2 Experiment for evaluating the accuracy and stability in the case that only single marker is used

5.2.1 Experimental Method

A circular marker which diameter was 40mm was pasted on a small box. The number of the division of middle circle was 8, 9 and 10. The camera was fixed horizontally and the marker was captured in the center of the image. The initial distance between the marker and the camera was 300cm and initial angle was 0 degree. In the experiment, the distance was changed to 580cm with 20cm step, while the angle was changed to 75 degrees with 15 degrees step. For each condition, 100 images were captured and the position and orientation was calculated. The average and the variance were calculated.

Table 1: Specification of Hardware Components

<table>
<tr><th>Component</th><th>Model</th><th colspan="2">Specification</th></tr>
<tr><td rowspan="6">CCD Camera</td><td rowspan="6">Sony XCD-X710</td><td>Resolution</td><td>1024 x 768</td></tr>
<tr><td>Color</td><td>Grayscale 8bits per pixel</td></tr>
<tr><td>Focal length</td><td>8mm</td></tr>
<tr><td>White balance</td><td>Manual</td></tr>
<tr><td>Exposure</td><td>Manual</td></tr>
<tr><td>Interface</td><td>IEEE 1394b (IIDC Ver1.30)</td></tr>
<tr><td rowspan="3">PC</td><td rowspan="3">DELL Workstation PWS360</td><td>OS</td><td>Windows XP Professional</td></tr>
<tr><td>CPU</td><td>Pentium4 3.0GHz</td></tr>
<tr><td>Memory</td><td>1GB</td></tr>
</table>

5.2.2 Experimental Result

Figure 3 shows the example of the captured image (the distance between the marker and the camera was 560cm and the angle was 0 degree). Table 2 shows the maximum distance the marker can be recognized. Figure 4 and 5 shows the errors of position estimation and result of angle estimation respectively. The maximum variance of the distance was 94.5mm and the maximum variance of the angle was 2.1 degrees. The frame rate of the processing was 30 frames per second, which was the maximum rate of the camera image translation from the camera to the PC (CPU usage was about 95%). As Fig. 4 shows, the accuracy of position estimation was really bad when only one marker was used for the calculation.

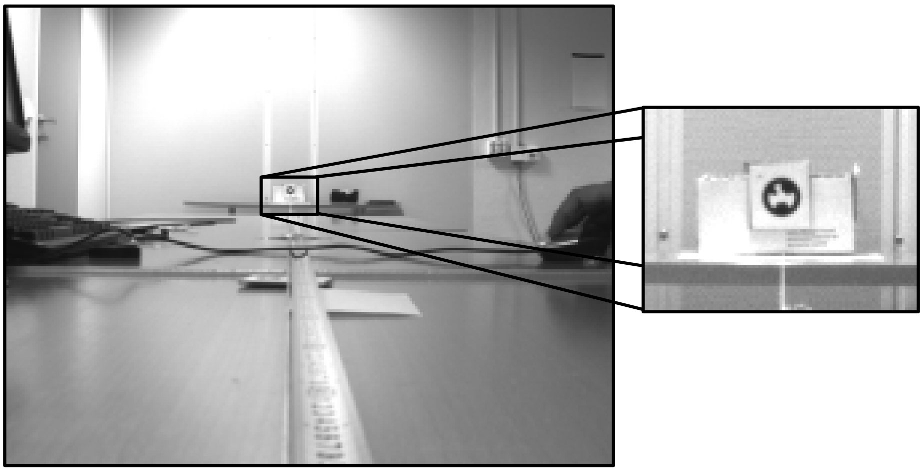

Figure 3:Example of the captured image (Distance:560cm, Angle:0 degree).

Table 2: Maximum distance (diameter is 4cm)

Number of Division	Angle (deg.)					
	0	15	30	45	60	75
8	520/560	520/560	500/560	440/520	380/440	X/300
9	520/560	520/560	500/560	440/520	380/440	X/X
10	520/560	520/560	500/560	400/500	380/420	X/X

Recognition succeeded in all frames(cm) / Recognition failed in some frames(cm)

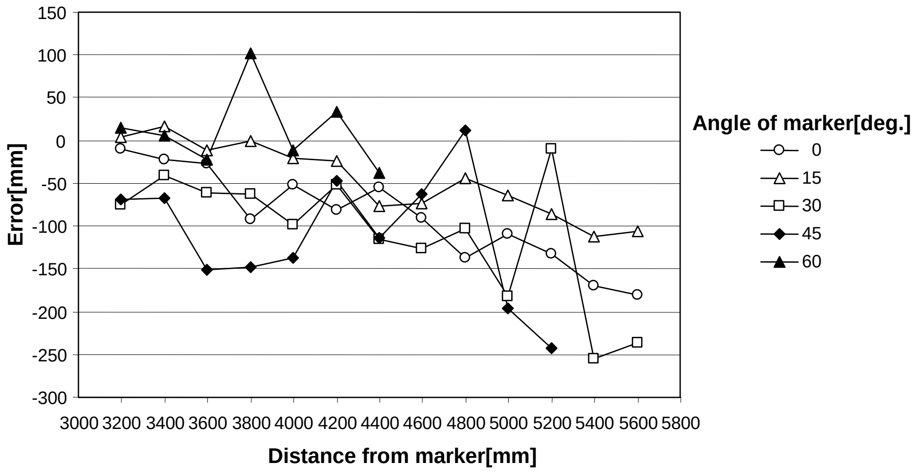

Figure 4: Errors of position estimation. (Single marker)

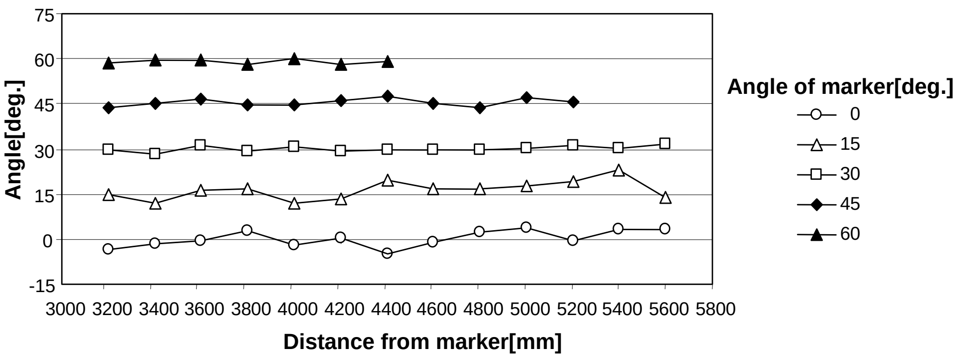

Figure 5: Results of angle estimation. (Single marker)

5.3 Experiment for evaluating the accuracy and stability in the case that plural markers are used

5.3.1 Experimental Method

22 circular markers were pasted on a helmet as shown in Figure 6. The number of the division of middle circle was 8. The camera was fixed horizontally and the helmet was captured in the center of the image. The initial distance between the helmet and the camera was 300cm and initial angle was 0 degree. In the experiment, the distance was changed to 560cm with 20cm step, while the angle was changed to 180 degrees with 15 degrees step. For each condition, 100 images were captured and the position and orientation was calculated. The average and the variance were calculated.

5.3.2 Experimental Result

Figure 7 shows the example of the captured image (the distance between the helmet and the camera was 560cm and the angle was 0 degree). Figure 8 and 9 show the errors of position estimation and result of angle estimation respectively. The maximum variance of the distance was 40.8mm and the maximum variance of the angle was 3.6 degrees. The frame rate of the processing was about 25 frames per second (CPU usage was 100%). As Fig. 7 and 8 show, the accuracy of position and angle estimation was improved compared to the case of the single marker.

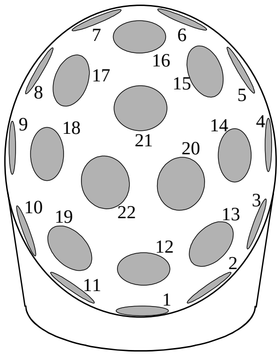

Figure 6: Layout of markers on helmet.

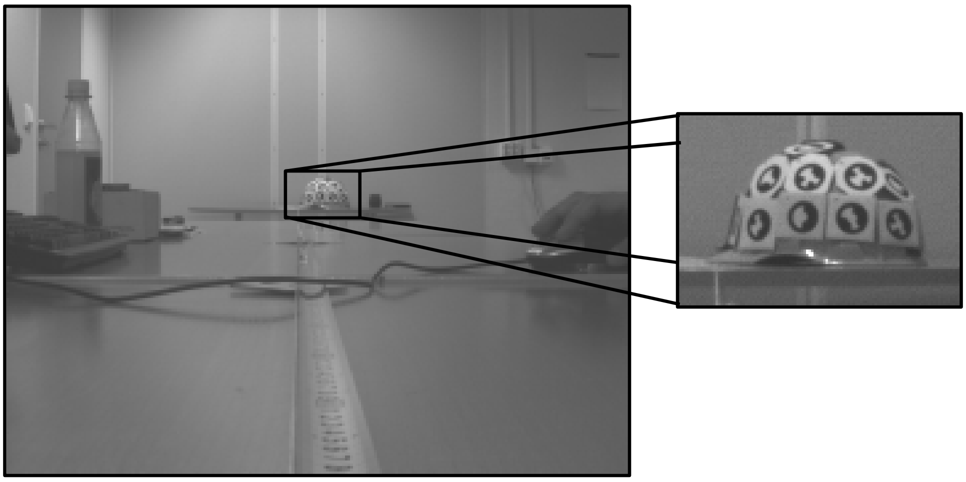

Figure 7: Example of the captured image (Distance:560cm, Angle:120 degrees).

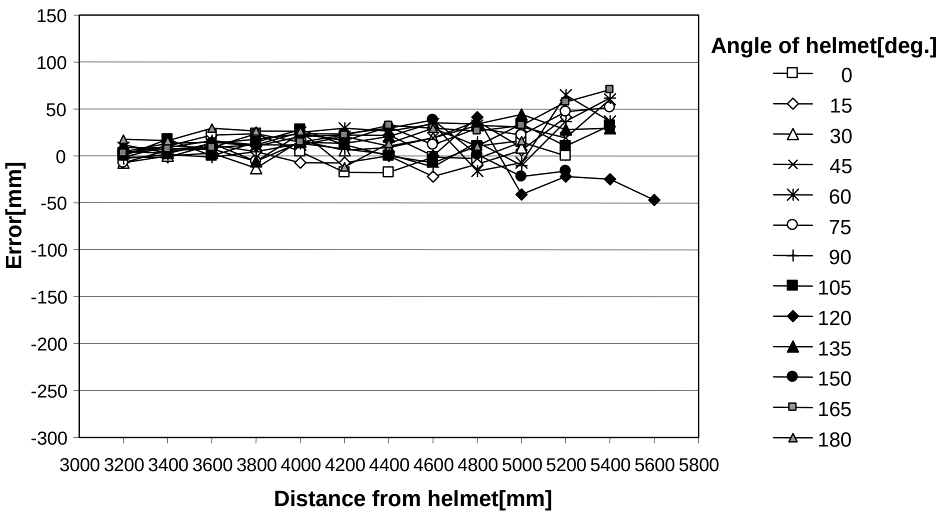

Figure 8: Errors of position estimation. (Plural marker)

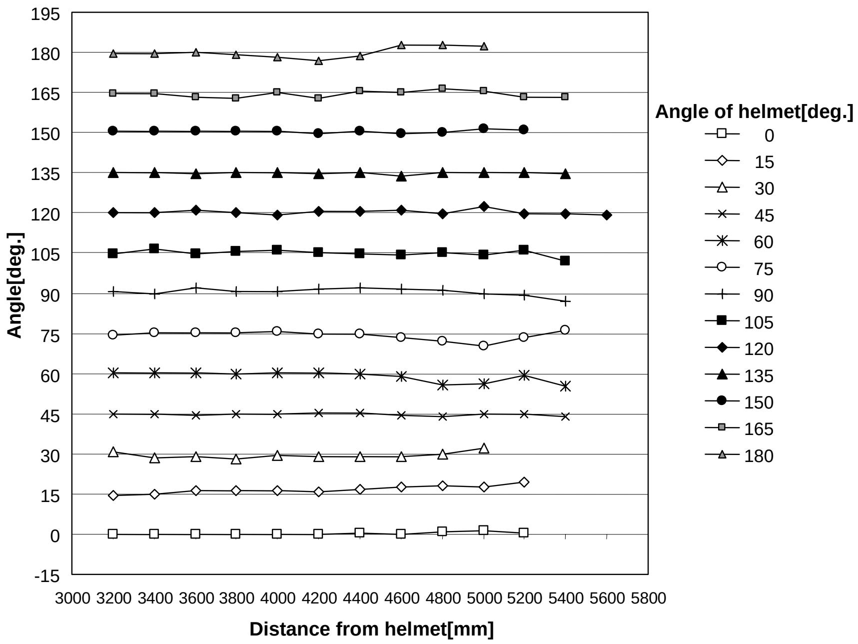

Figure 9: Results of angle estimation. (Plural marker)

5.4 Other example application of the tracking system

In this study, the evaluation was conducted only for the case that single marker is pasted on a box or plural markers are pasted on a helmet. The developed tracking system can be used for the other situation. One example is “Tracking in the office”. Figure 10 shows an example where plural markers are pasted on a wall and the position and rotation are calculated in real time and the result is transferred to Java3D application to visualize a virtual layout of the office. In this case, the markers are pasted on wide area and the distance between the markers is rather long, so the accuracy of the tracking is better than the case of the single marker and the helmet. As the result of rough estimation, the error of the position is less than 2cm when the distance between the markers and the camera is about 3m and a lens which focal length is 4mm is used.

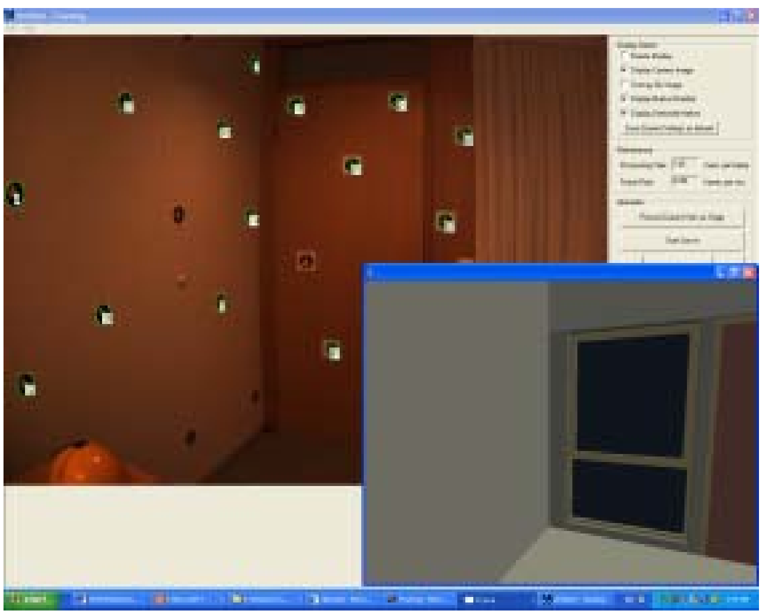

Figure 10: Tracking in the office.

6. Conclusion

In this study, a new circular marker has been designed and a tracking system that recognizes plural circular markers at one time and measures the position and rotation of the target with high accuracy has been developed. And some experiments have been conducted in order to evaluate the accuracy and reliability of the proposed method and it has been confirmed that the accuracy can be greatly improved by using plural markers at one time and the distance between the marker and the camera can be long compared to the conventional method.

As the future works, we have a plan to apply the developed tracking system to track workers in NPP and provide useful information such as radiation map of the plant. And we have also a plan to apply the developed tracking system to visualize an old church on a hill where the old church was exist in 17 century but currently only a part of the church remains.

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