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).

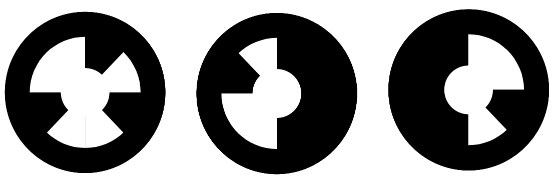

Figure 1: Example of circular markers (The code area is divided into 8 elements)

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.

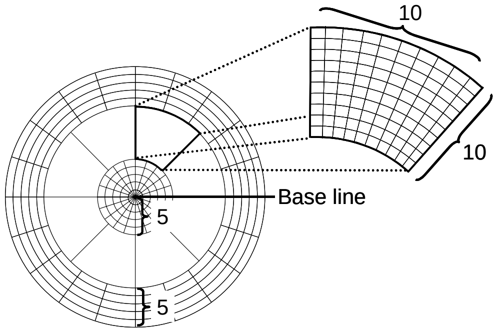

Figure 2: Normalize of circular marker (The code area is divided into 8 fans).

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

Component	Model	Specification	
CCD Camera	Sony XCD-X710	Resolution	1024 x 768
		Color	Grayscale 8bits per pixel
		Focal length	8mm
		White balance	Manual
		Exposure	Manual
		Interface	IEEE 1394b (IIDC Ver1.30)
PC	DELL Workstation PWS360	OS	Windows XP Professional
		CPU	Pentium4 3.0GHz
		Memory	1GB

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.

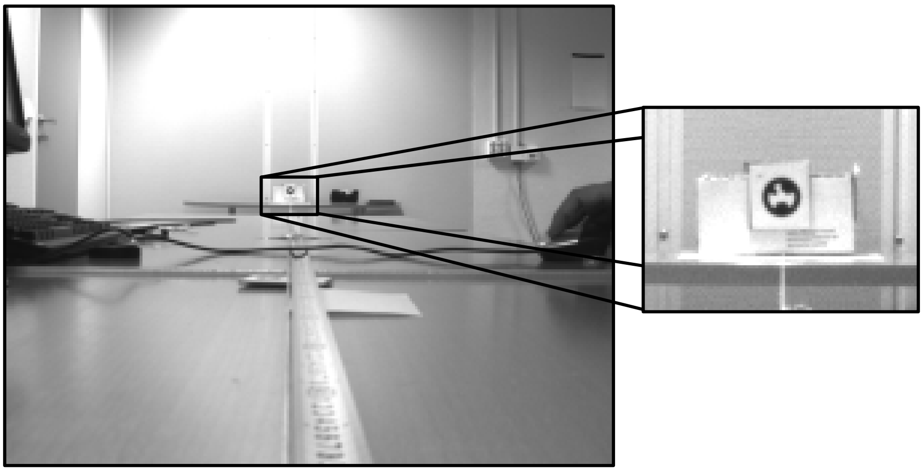

Figure 3:Example of the captured image (Distance:560cm, Angle:0 degree).

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)

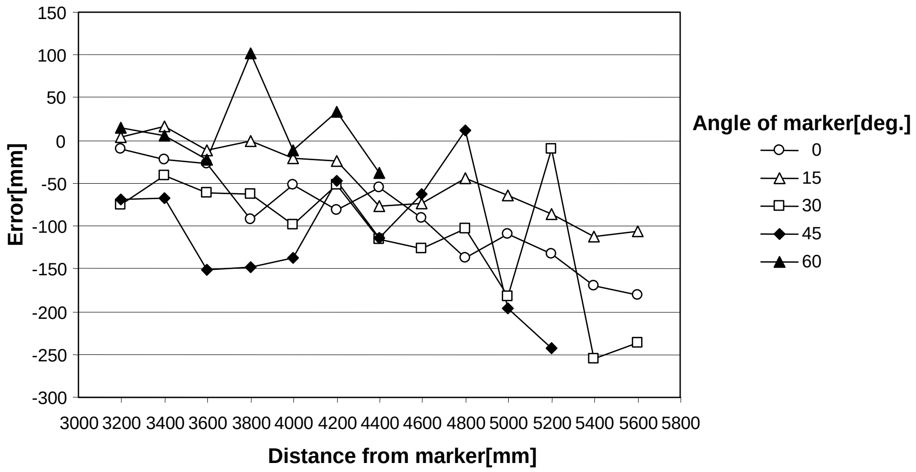

Figure 4: Errors of position estimation. (Single marker)

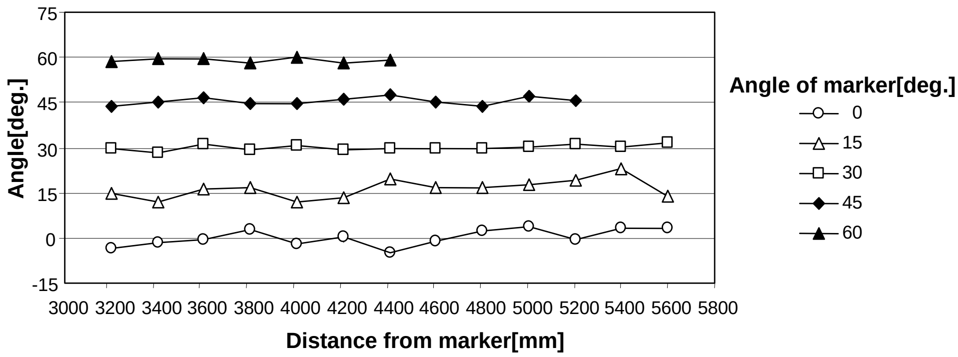

Figure 5: Results of angle estimation. (Single marker)

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.

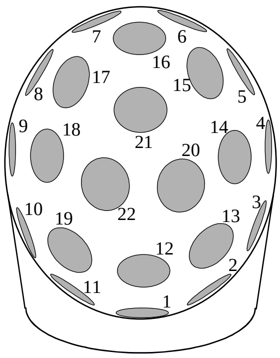

Figure 6: Layout of markers on helmet.

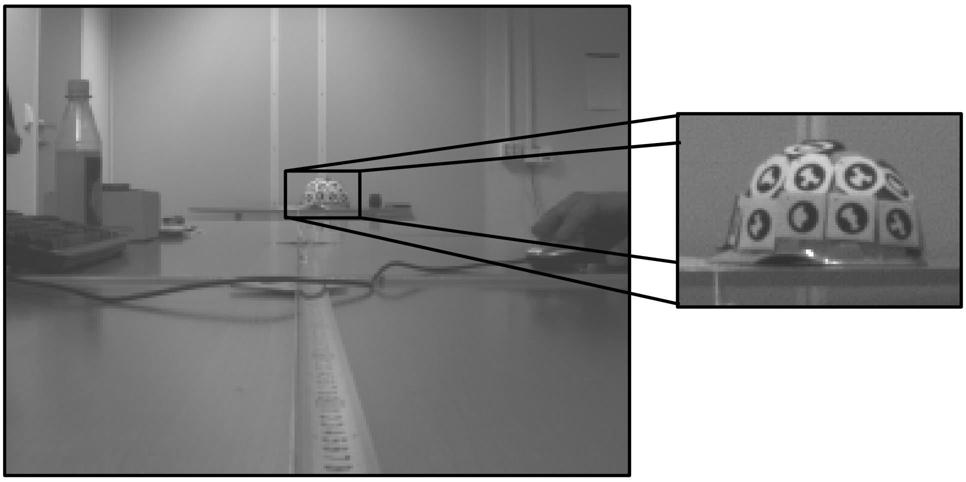

Figure 7: Example of the captured image (Distance:560cm, Angle:120 degrees).

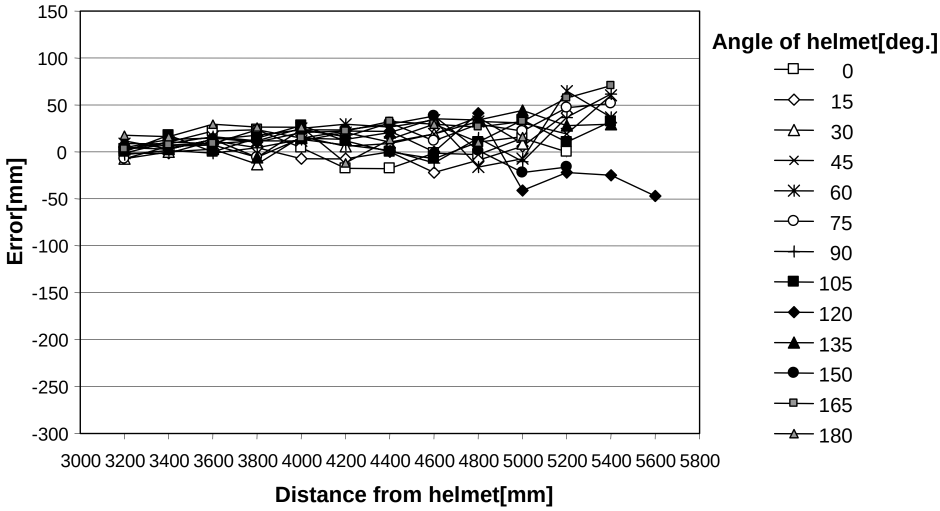

Figure 8: Errors of position estimation. (Plural marker)

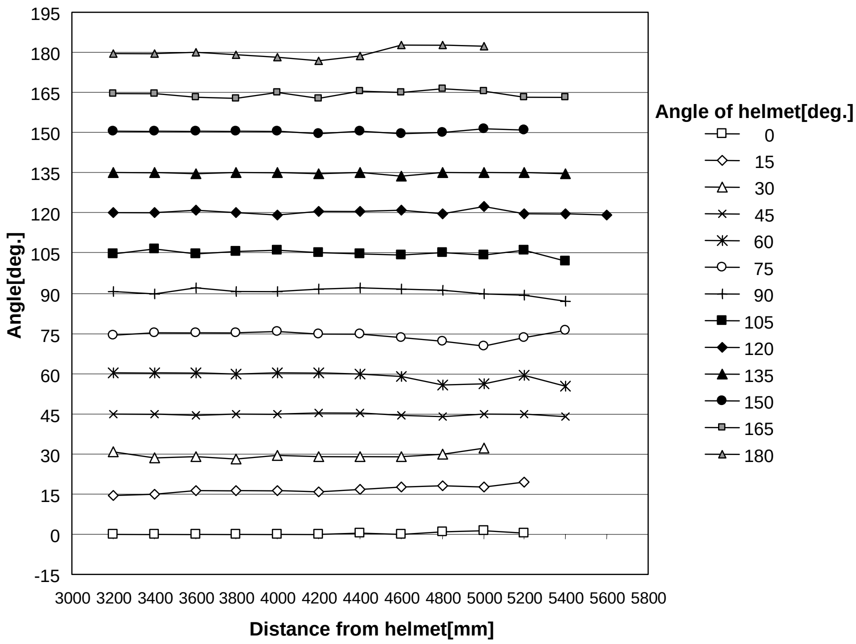

Figure 9: Results of angle estimation. (Plural marker)

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.

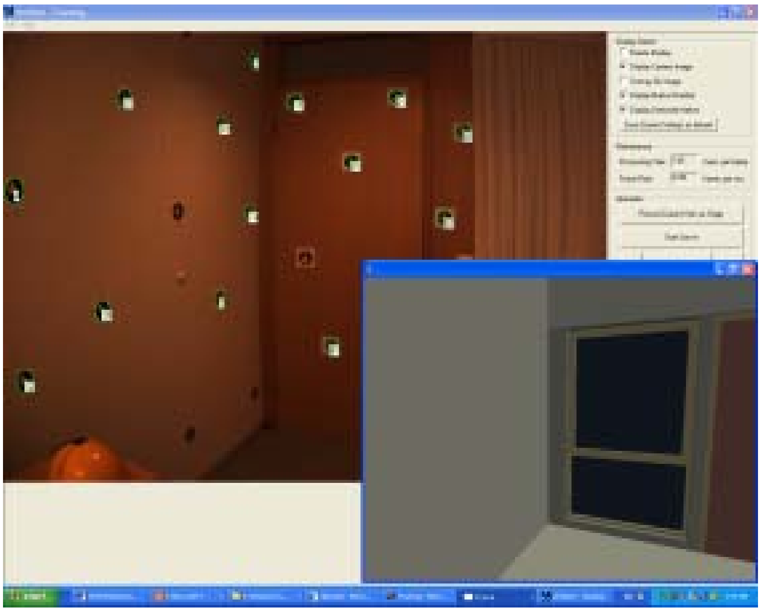

Figure 10: Tracking in the office.

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.

References

[1] M. Reigstad, and A. Droivoldsmo, "Wearable control rooms: New technology can change collaboration, communication and information flow in future field operations", Proceedings of the 22nd European Annual Conference on Human Decision Making and Control, 2003.

[2] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent Advances in Augmented Reality", IEEE Computer Graphics and Applications, Vol. 21, No. 6, pp. 34-47, 2001.

[3] J. Borenstein, H. R. Everett, L. Feng, D. Wehe, "Mobile Robot Positioning - Sensors and Techniques", Journal of Robotic Systems, Vol. 14, No. 4, pp. 231-249, 1997.

[4] N. Navab, "Developing Killer Apps for Industrial Augmented Reality", IEEE Computer Graphics and Applications, Vol. 9, No. 3, pp. 16-20, 2004.

[5] Y. Genc, S. Riedel, F. Souvannavong, C. Akinlar, N. Navab, "Marker-less Tracking for AR : A Learning-Based Approach", Proceedings of the International Symposium on Mixed and Augmented Reality, pp. 295-305, 2002.

[6] H. Kato and M. Billinghurst, "Marker tracking and HMD calibration for a video-based augmented reality conferencing system", Proceedings of IWAR, 1999.

[7] S. Feiner, B. MacIntyre, and D. Seligmann, "Knowledge-based Augmented Reality", Communications of the ACM, Vol. 36, No. 7, pp. 52-62, 1993.

[8] S. Feiner, B. MacIntyre, M. Haupt, and E. Solomon, "Windows on the World: 2D Windows for 3D Augmented Reality", Proceedings of UIST '93, pp. 145-155, 1993.

[9] E. Foxlin, M. Harrington, and Y. Altshuler, "Miniature 6-DOF Inertial System for Tracking HMDs", SPIE Helmet and Head-Mounted Displays III, Vol. 3362, 1998.