On accuracy of 3D localization obtained by aligning 3D model with observed 2D occluding edges

Abstract

In this paper, accuracy of the 3D localization obtained by aligning a 3D model with 2D observed occluding edges is discussed on. Aiming at accurate localization of a robot in a nuclear power plant, a method for aligning a 3D environmental model with an image observed by a camera mounted on the robot was proposed [1]. By effectively using the two-type predicted views which are calculated by a graphics system (eg. OpenGL etc), the method succeeded in robust alignment even though the scene consists of complicated occluding edges of pipes. However, accuracy of the 3D localization obtained by the alignment has not been yet enough examined. In this paper, some factors affecting the error in the 3D localization are elucidated. The experimental results using both synthetic and actual data make clear that the error in the angle of the field of view of the camera model causes relatively large translation error in the view direction. For the case the camera parameter is not known precisely, we propose to utilize two cameras to decrease the errors and show its effect.

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1 Introduction

When the task of inspecting some environment is given to a robot, it is effective that the robot freely changes view points while freely moves around. Based on this philosophy, we have mounted a high-performance active camera head on a mobile robot aiming at autonomous inspection of nuclear power plants. Here, it is quite important to accurately know the position and pose of the camera head both to navigate the robot in a narrow space among the pipes and to carry out precise inspection. Therefore, we aim at visual feedback to correct inaccurate state of the camera head obtained from dead reckoning.

Since a 3D model of the environment surrounding a robot is given in our application, the 3D localization of the camera head can be done by aligning the 3D model with an observed image. Although some methods have been proposed for the 3D-2D alignment [2] [3], these are not directly applicable to our subject because of the complexity of observed occluding edges caused by many pipes in the plant. This difficulty was overcome by the method proposed in[1]. The method succeeded in robust 3D-2D alignment even in complicated scenes by effectively using the two-type predicted images which are calculated from the 3D environmental model by a graphics system (eg. OpenGL etc). However, accuracy of the 3D localization lead from the alignment result has not been yet enough examined.

In this paper, we investigate the accuracy of the 3D localization. The effects of some factors deteriorating the localization accuracy are simulated with synthetic observed edges. We show that the error in the angle of the field of view of a camera model causes a big translation error in the view direction. Then, for the case that we cannot precisely know the correct angle of the field of view, we propose to utilize two cameras to decrease the errors and consider about how to set the cameras. In Section 2, the basic scheme proposed in [1] is briefly explained. In Section 3, some factors affecting the localization error are analyzed. Then, the effect of the use of two cameras in decreasing the localization error is shown through the experiments using both synthetic and actual data in Section 4.

2 Basic Scheme of 3D-2D alignment[1]

Fig. 1 shows a scheme of our strategy for determining the position and pose of a camera by aligning the 3D model with occluding edges in an observed image [1]. First, the 3D model points corresponding to the observed edges are calculated from the 3D environmental model and the initial estimated state of the camera (eg. data from dead reckoning). This process is done rapidly by using the two-type predicted images, view and depth images, calculated by a graphics system (eg. OpenGL). Next, based on the closeness between the projected 3D model points and the observed edges on the image, 3D-2D point correspondences are determined. The current position and pose of the camera is renewed to satisfy the 3D-2D point correspondences. The correct camera state is obtained by iterating the point matching and camera transformation processes.

Fig. 2 shows one example of the processes. In Fig. 2a, the projection of the model on the observed image is deviated because of the error in the initial estimation of the camera state. White points in Fig. 2b show 3D model points calculated from the predicted views. In Fig. 2c, the model points are overlaid on the observed edge image calculated with Canny operator[4].

The grey levels of the model points and the edges illustrate their directional attributes which are classified into eight directions. For the model points, the maximum gradient directions around the projection of the 3D model points in the predicted intensity image are used to determine the attribute. Only at the first iteration, the projected 3D model points are two dimensionally translated on the image to search for the best position where the model points overlapped on the edges with the same direction attribute, since a little change in camera angle causes a big translation in the image. Fig. 2d shows the position after this initial translation. White lines connecting the model points and edges in Fig. 2d show the 3D-2D point correspondences which are basically determined based on the the closeness on the image [5]. The camera is moved to satisfy these correspondences. At the new state, the same processes except the 2D translation on the image are iterated until the camera state converge. Fig. 2e, f shows the model projection after convergence. The computational time is about a few sec (Pentium II(333MHz)).

3 Investigation on accuracy in 3D localization

3.1 Accuracy in 3D localization

We examined accuracy of the 3D localization calculated from the 3D-2D alignment method by comparing with manual measurement. Fig.3a shows our experimental environment, a plant-mockup. A robot with an active camera head moves around in the environment. 17 pipes in this environment are selected and modeled with cylinders in OpenGL as shown in Fig.3b.

Fig. 4a shows an example of the images observed by a camera mounted on the robot. The position and pose of the camera head was manually measured and illustrated in the top view of

Fig. 4b: the white circle and the white line sticking out from the circle illustarte the position and the view direction respectively. The accuracy of the manual measurement is about ± 5mm in translation and ± 3 degrees in rotation. Because of this slight error, the projection of the model at the state shows a little deviation from the observed image as shown in Fig. 4b. The 3D world coordinate system is defined as shown in Fig. 2b so that the x and z axes lie in the horizontal floor face; the y axis completes the left-handed coordinate system, and is in the vertical direction.

We intentionally add some errors to the camera state and use it as the initial estimate. Fig. 4c shows the projection of the 3D model when giving the camera state after adding (50,0,50) mm translation and 5 degree rotation around the y axis to the measured state. In the top view, the white circle shows the current camera position, while the gray circle overlapped by the white circle shows the measured state. Fig. 4d shows the result after correcting the camera state by the method described in Section 2. The model is well aligned with the image. Nevertheless, as shown in the top view, the translation error occurred mainly in the view direction, which is about 90 mm.

We have done similar experiments using more than 10 images observed at various locations. In all the experiments, 3D localization is well converged close to the correct state. This showed the robustness of the method in such a complex scene. However, the translation error in the view direction appears in all cases.

3.2 Effect of pixel quantized error

When estimating 3D information from a 2D image, it is general that the accuracy becomes worse in the view direction. Therefore, we first suspected that the pixel quantized error may cause this big deviation in the view direction. To analyze the effect of the pixel quantized error, we conduct the following synthetic experiments. First, the observed edges are synthetically calculated by projecting model data as shown in Fig. 5a. The 3D-2D alignment method is applied to this synthetic edge image. The correct state is given as the initial estimate so that the transformation from the initial state directly shows the effect of pixel quantized error. Fig. 5b shows projected model points converging on the synthetic observed edges.

From the results of this experiment, it was found that the error in the 3D location caused by the quantized error is small: the translation and rotation errors are about 0.6 mm and 0.03 degrees. This accuracy is supported by the fact that the method uses lots of 3D-2D corresponding pairs which distributed in a whole image. Actually, if only 9 pairs of the 3D-2D correspondences are used, the translation and rotation errors become about 11 mm and 0.4 degrees. Additionally, the effect of using distributed pairs was assured by the observation that the translation and rotation errors become about 4 mm and 0.08 degrees if we use the 3D-2D pairs only from two pipes, one vertical one and one horizontal one.

3.3 Effect of inaccuracy of the angle of the field of view

Through similar synthetic experiments, the effect of inaccuracy of the angle of the field of view of a camera model was examined. This time, synthetic observed edge images are calculated from the model projection obtained with the angle of the field of view which slightly different from the camera model of the 3D-2D alignment method. This simulates that the angle of the field of view of the camera model which the method use to predict the view and depth images is a little different from the actual camera.

Fig. 6 shows the result when giving a smaller angle for synthetic views. The localization of the camera becomes closer in the view direction just as we experienced in the actual experiments. When giving a larger angle, the location deviated further in the view direction. In the situation in Fig. 6, the magnitude of the translation error in the view direction is about -45mm per one degree error of the angle of the field of view.

After this observation, we carefully measured the angle of the field of view of the actual camera we use and found it is about 48 degree, although we had used 50 degree based on the camera specification. In the case of data in Fig. 4, translation error in the view direction is decreased from 90 mm to 4mm by correcting this camera parameter.

4 Usage of two cameras for error compensation

Although the translation error in the view direction can be decreased by using accurate angle of the field of view, it is sometimes difficult to know the accurate values especially when a robot need to change the camera focus and/or zoom during a sequential task. Therefore, in this section, we think about a way to compensate the error. From the point that the translation error is in the view direction, additional observation by another camera which has the view direction perpendicular to that of the first camera is thought to be effective to decrease the error. Actually, this addition is easy in our application since active stereo camera head is mounted on the robot for carrying out various tasks.

First, we synthetically simulated the effect of using two cameras. Fig.7a shows the left and right synthetic edge images of the parallel stereo cameras which are set as shown in the top view.

Here, the synthetic edges are calculated using 48 degree as the angle of the filed of view.

The method is applied with a false angle of the filed of view, 50 degree, two degree bigger than the actual one. The resultant translation and rotation errors were examined while panning the left camera outward at the same position. Fig.7b shows the left and right image and the camera state after 90 degree panning. The results are summarized in Table 1. The second line of Table 1 shows the result when using the right image only. From the third line of Table 1, the result when using the left image only and that when using the two images simultaneously are shown alternatively. Combining the 3D-2D correspondences obtained from two (or more) observed images can be done as shown in [5]. The cause of the dispersion of the magnitude of translation errors is that the observed objects are changed by the panning. As shown in Table 1, the translation errors in the view direction are always improved by using two images except parallel stereo camera setting (pan angle = 0). The improvement ratio becomes higher when the angle between the view lines of the two cameras gets close to the right angle. This effect clearly appears in the difference between the the results of Fig.7a and b.

Next we examined the effect of two cameras by using actual images in Fig.8. Fig.8a shows the results using the two images of parallel stereo cameras. The translation error in the view direction was 45.4 mm. Fig.8b,c show the results using the images taken by the two cameras set so that the angle of their view directions becomes 45 degree. If we use the right image only to calculate the 3D location, the resultant position was deviated in the view direction of the right camera as shown in the top view of Fig.8b. The translation error in the view direction is 42.0 mm. As a result, the model projection on the left image at the resultant state deviated from the observed image. On the other hand, in the case we use the two images simultaneously, the translation error in the view direction are decreased to 16.0 mm as shown in Fig.8c.

5 Conclusion

In this paper, we elucidated some factors affecting accuaracy of the 3D localization obtained by aligning a 3D model with observed 2D occluding edges. Simulation of inaccurate angle of the field of view clarified that the error in the angle brings relatively large traslation error in the view direction. For the case the camera parameter is not known precisely, we proposed to utilize two cameras to decrease the errors. The experiments using both synthetic and actual data showed that the use of two cameras improves the localization accuarcy especially when the angle of their view directions becomes closer to the right angle.

References

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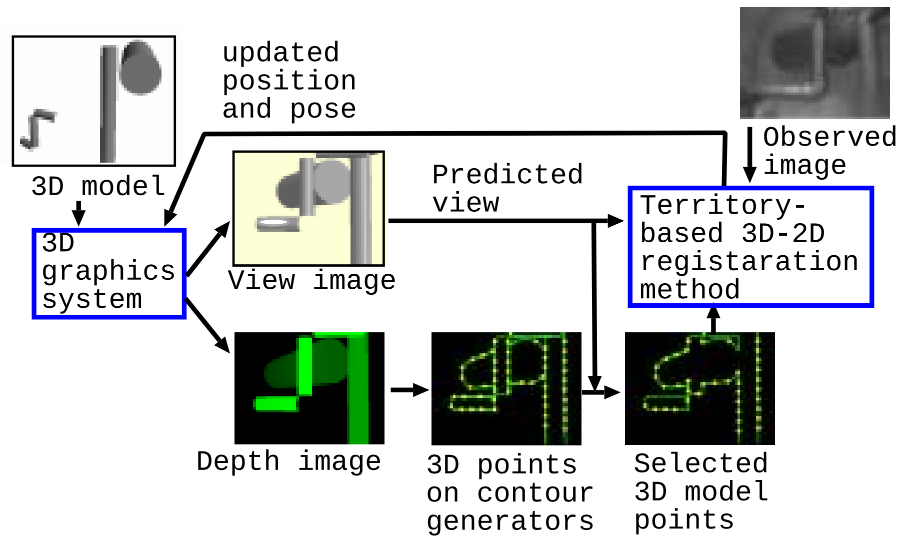
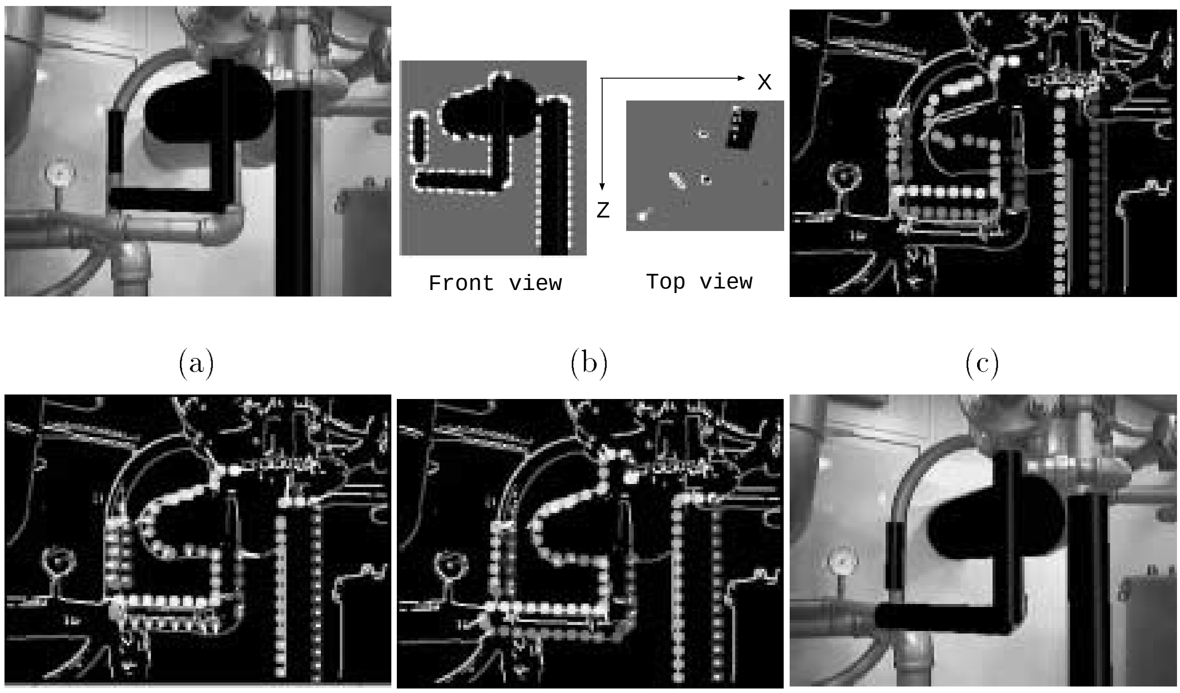


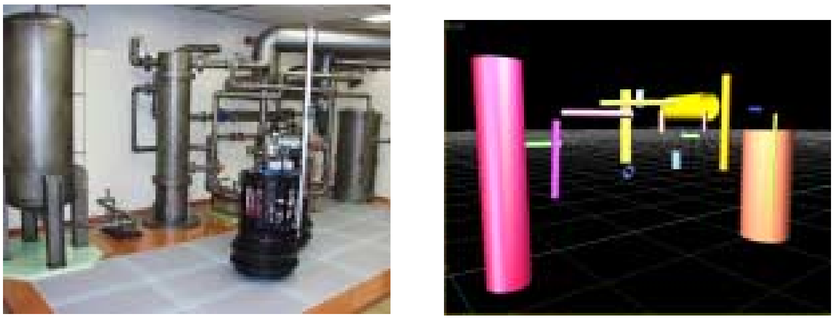
Figure 1: Scheme of determination of the position and pose of a camera using occluding edges



(a) (b) (c)

(d) (e) (f)

Figure 2: Example of processes of 3D-2D alignment: (a) projection of the model at the initial estimated state; (b) front and top views of the 3D model points (white points); (c) projection of the 3D model points on the observed edge image; (d) projection of the 3D model points after initial 2D translation; (e) projection of the 3D model points after convergence; (f) projection of the 3D model after convergence.



(a) (b)

Figure 3: Experimental environment: (a) plant-mockup; (b) its partial models consisting of 17 cylinders.

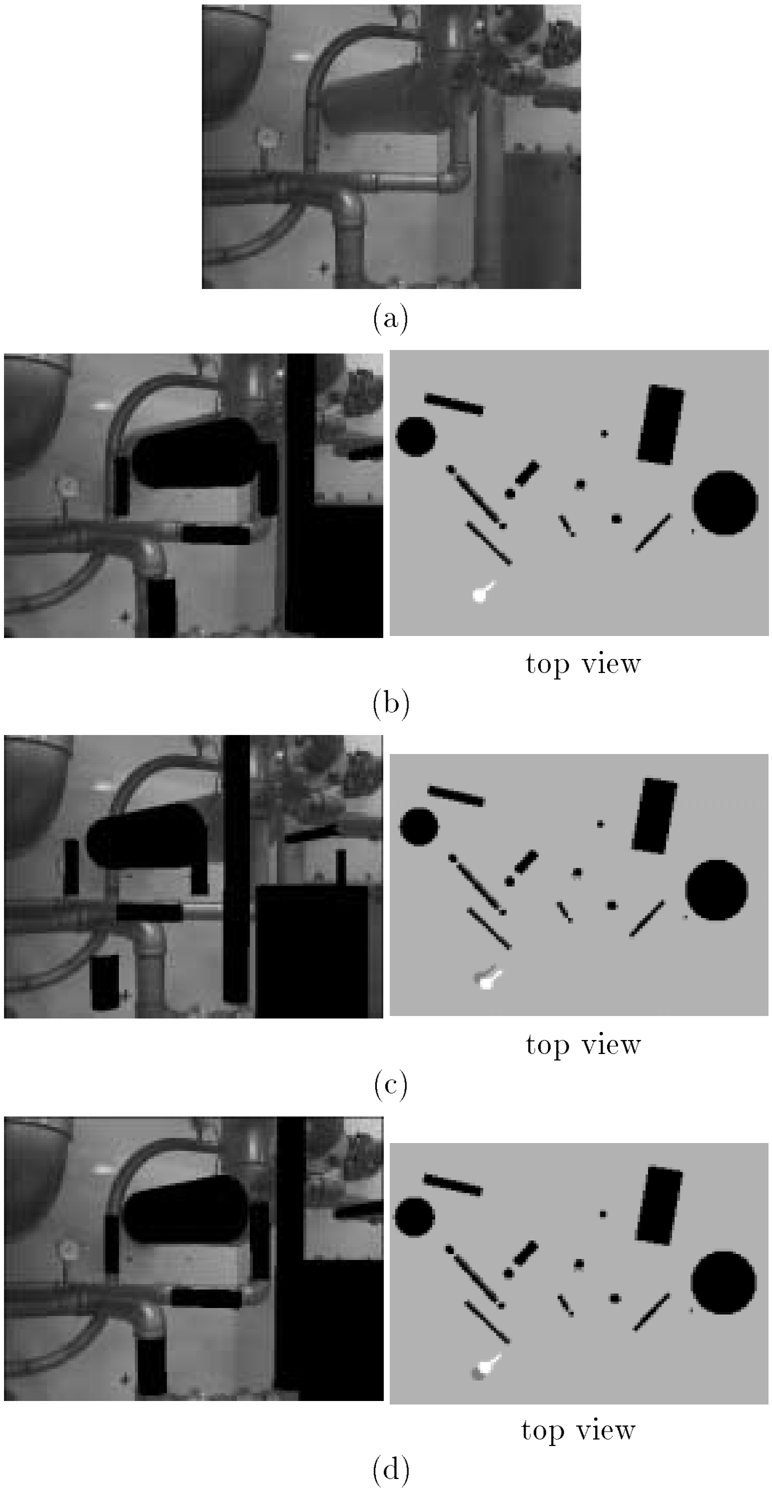
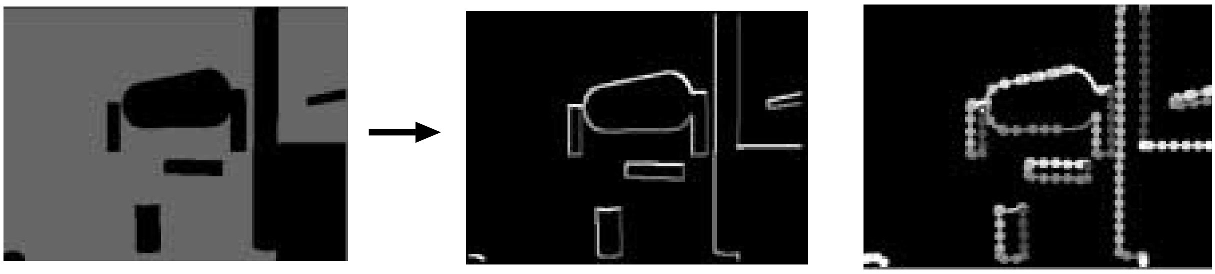


Figure 4: Example of localization result: (a) observed image; (b) measured state; (c) initial state; (d) result



(a) (b)

Figure 5: Experiment for investigating pixel quantized error: (a) calculation of synthetic observed edges; (b) projection of model points after convergence

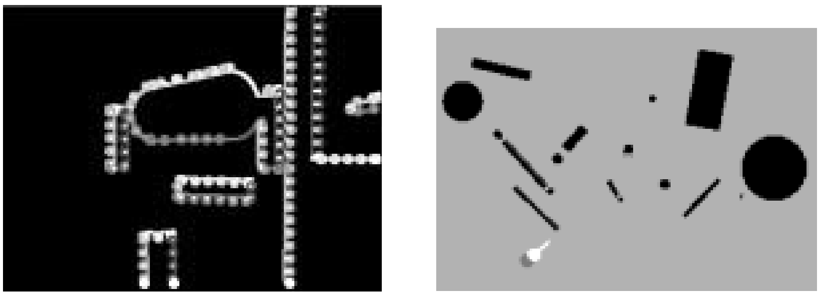
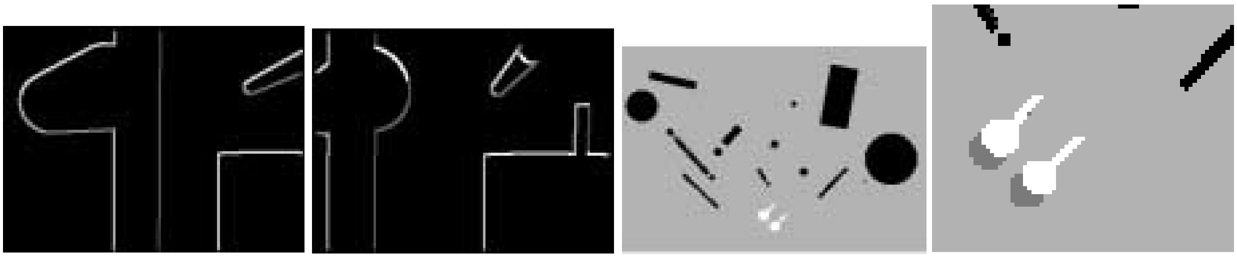
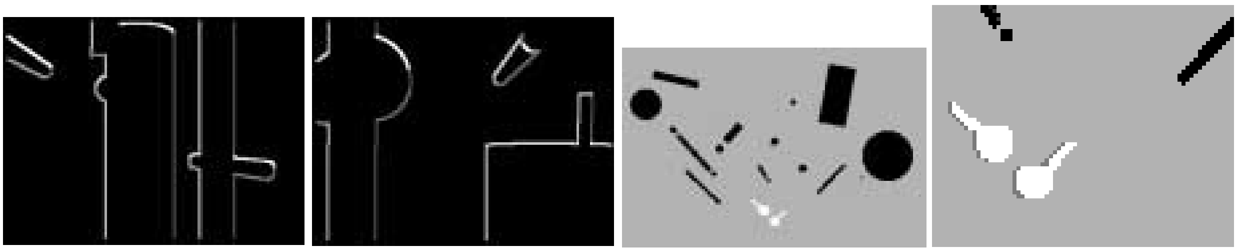


Figure 6: Effect of error in angle of the field of view



left image | right iage | top view | result

(a) pan angle of left image = 0



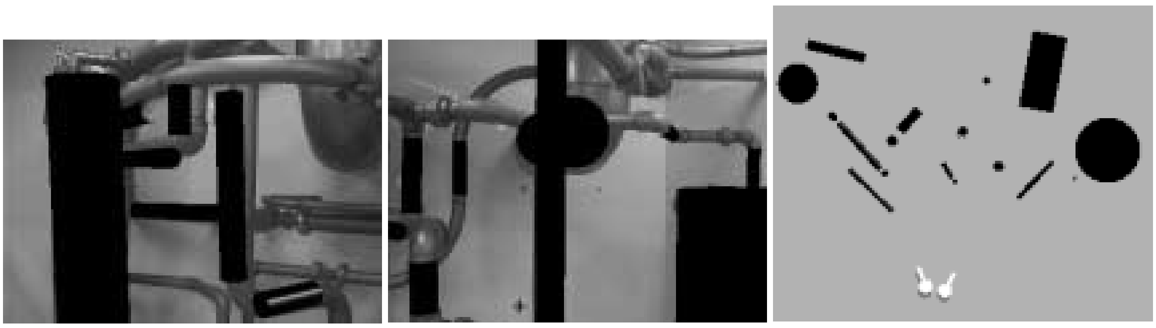
left image | right iage | top view | result

(b) pan angle of left image = 90

Figure 7: Experiments on effect of using two cameras (synthetic data)

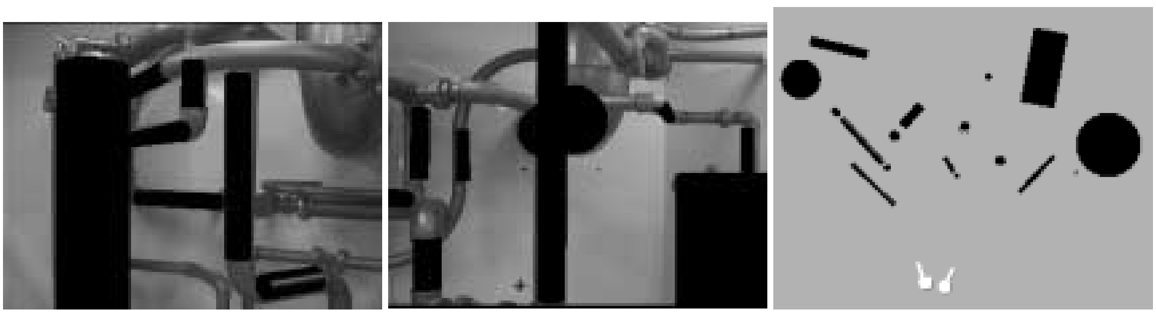
left image right image top view

(a)



left image right image top view

(b)



left image right image top view

(c)

Figure 8: Experiments on effect of using two cameras (actual data)

Table 1 Localization errors caused by the inaccurate angle of the field of view of camera: 50 degree is used in the 3D-2D alignmemt method, while the synthtic observed edges are calculated using 48 degree.

angle of the view directions	used image for localization	magnitude of total trans. error (mm)	trans. error in the view direction (mm)	rot. error (deg.)
-	R	58.2	-55.7	0.7
0	L	76.1	-74.6	0.6
0	L,R	59.7	-58.8	0.4
20	L	33.7	-32.6	0.5
20	L,R	29.1	-29.1	0.2
40	L	30.1	-29.6	0.7
40	L,R	15.8	8.7	1.1
60	L	19.7	-16.0	1.3
60	L,R	11.5	-10.2	0.7
80	L	59.0	-57.7	0.6
80	L,R	20.2	4.4	0.6
90	L	55.5	-55.0	0.2
90	L,R	16.5	11.7	0.7