EASY PROJECTOR AND MONOCHROME CAMERA CALIBRATION METHOD USING PLANE BOARD WITH MULTIPLE ENCODED MARKERS

Tatsuya Hanayama[1] Shota Kiyota[1] Ryo Furukawa[3] Hiroshi Kawasaki[1]
[1]Faculty of Engineering, Kagoshima University, Kagoshima, Japan
[3]Faculty of Information Science, Hiroshima City University, Hiroshima, Japan

ABSTRACT

In recent years, development on 3D measurement system using a projector and a camera becomes popular. One critical issue for the system is a calibration of the devices, because projector cannot capture an image, and thus, indirect way to get correspondences between a pixel of the pattern and a 3D point in the scene is required. Typical solution is to capture a special calibration object on which temporally encoded patterns are projected by a projector. Since the process is usually complicated and take a time, efficient method is investigated and a plane based technique has been developed. In the paper, we extend the plane based method by using a set of spatially encoded pattern for robust detection. We also propose an adaptive binarization and global optimization method for efficient detection of overlapped markers. Experimental results are shown to prove the effectiveness of the method.

1. INTRODUCTION

Recently, active stereo method has been used for wide areas, such as inspection, movie creation, etc. An active stereo method measures 3D shapes by projecting lasers or structured lights onto the object and capturing the scene by a sensor. Among them, projector-camera system becomes popular because of its simplicity, high accuracy and density.

In general, accurate measurement of active stereo method requires strict calibration of the devices in advance. Although a number of practical solutions are available for camera calibration, there are few for projector. Since the optical system of projector is same as that of camera, camera calibration algorithms can be used. However, since a projector cannot capture a scene, correspondences between a pixel of the pattern and 3D point in the scene should be acquired in an indirect way; *e.g.*, capturing a set of projected patterns by a camera and decoding them. To encode the positional information into the pattern, two methods are known; temporal and spatial methods. Since temporal methods require multiple projections of patterns, all the devices must stay still during the capture and it is not a easy task. To the contrary, spatial methods, which allows users to freely move the calibration objects during the process, do not have such limitation. Therefore, spatial method is used in the paper. Another important requirement is that black and white camera is frequently used for industrial purpose.

To satisfy the requirements stated above, we propose an efficient calibration method using a planar board with a set of small markers, *i.e.*AR marker in the paper [1]. The actual calibration process is as follows. We capture the planar board which AR markers are printed on and the similar patterns are projected by a projector. Those overlapped patterns are efficiently separated by our method, and then, simultaneous calibration of the camera and the projector is conducted. Contribution of our method are as follows:

1. Distinctive AR marker design to realize better identification for calibration is proposed.
2. To mitigate mis-detection caused by uneven reflection on the board because of the slanted plane, adaptive binarization technique is proposed.
3. Global optimization method to efficiently separate the overlapped patterns is proposed.

With the method, easy calibration of projector-camera system is possible without using special devices by simply projecting a static pattern onto the planar board.

2. RELATED RESEARCH

Historically, temporal coding technique with 3D calibration objects (typically a square box) has been conducted to calibrate projector-camera system [2]. One major drawback of the method is a preparation of calibration objects. For example, construction of the box with $1m$ high for human body scan is practically difficult. Recently, plane based methods are proposed for solution [3]. Since the methods utilize the algorithm for camera calibration, it usually requires 20 to 40 shots of the plane with different poses. Further, since the methods are based on temporal coding, multiple projections are required to get correspondences for each shot, and thus, more than hundred images are necessary for calibration.

To avoid such complicated task, spatial methods become popular [4]. With the method, checker board pattern is projected onto the planar board and the pattern is detected by common libraries. Since entire pattern should be captured for stable detection and it is not easy to project the entire

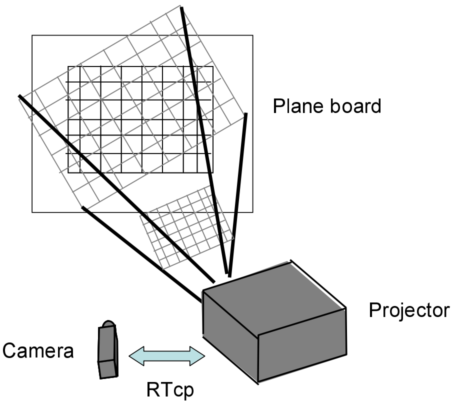
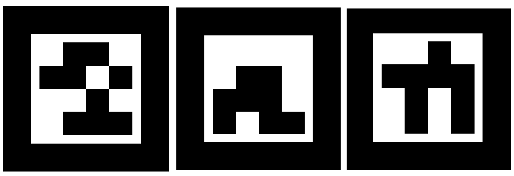


Figure 1: Setup of Camera and Projector.

(a) Classic AR markers [1]



(b) Our original AR markers

Figure 2: Example of AR markers.

pattern onto the limited size of the board, the quality of the calibration is unstable. We provide a simple solution for the problem.

There are several attempts which calibrate a projector with special approaches [5, 6]. Audet *et al.* propose a method using a local markers with feedback from a camera [5] and Drareni *et al.* propose a self-calibration method using marker-less planar object [6].

3. OVERVIEW

3.1. SYSTEM CONFIGURATION

The configuration of the camera, the projector and the calibration object for the proposed method is shown in Fig. 1. The planar board with a static pattern is used as the calibration object. Then, static pattern is also projected onto the board to calibrate the projector-camera system. The images used for the calibration are obtained by capturing the planar board. Since two patterns are overlapped each other on the board, the robust separation algorithm of the pattern is required. Note that, for image capturing process, it is preferable to widely move and rotate the planar board to increase the variation of the depths of feature points for better calibration; such condition makes it difficult to achieve robust marker detection. Efficient solution for partially captured pattern and/or strong specular reflection by projector is proposed in the paper.

3.2. ALGORITHM

The proposed method is divided into four steps. First, images required for calibration is captured by the camera. In the method, the AR marker is printed on the planar board and the same pattern is projected onto the board by the projector. Since the calibration cannot be done with the images overlapping two patterns each other, those patterns should be decomposed. Therefore, in the second step, decomposition of two patterns is efficiently conducted by using the subtle differences of the intensity of the patterns. In the method, one of the patterns is first detected and extracted, and then, the other pattern is retrieved afterwards using the first extracted pattern. In the third step, we detect markers from each patterns. In the step, auto-detection of the marker is done by using ARToolKit [1], respectively. Using the coordinate of the detected pattern, intrinsic calibration of the camera and the projector is done and the initial values are estimated. At the final forth step, the relative position of the camera and the projector as well as the intrinsic parameter are optimized by minimizing the reprojection error.

4. DETECTION OF MARKERS FROM OVERLAPPED PATTERN

4.1. DISTINCTIVE PATTERN DESIGN AND COLOR

To utilize the common libraries for pattern detection, previous methods use a checker pattern [4]. To mitigate the severe restriction on capturing process where the entire pattern must be captured, we propose a pattern which consists of a number of small markers. In our method, we used 63 different AR markers aligned 7x9. However, the calibration accuracy will be drastically reduced, if ID of the marker is wrongly detected. In order to keep enough uniqueness for all the markers, new AR markers are designed. Standard markers usually use a letter or a picture for easy detection as shown in Fig. 2(a), whereas our AR marker consists of a barcode-like 2D markers as shown in Fig. 2(b). The markers were created using a 0/1 flags within a 5x5 block to maximize the minimum Hamming distance between the markers.

In the method, two patterns are required: The pattern for a planar board and the pattern for projection. Since those patterns are overlapped each other, gray color is assigned to the dark region instead of completely black to make it

Table 1: Intensity of reflectance.

Image Board Intensity		Projector Dark 0.2	Projector Bright 1.0
Dark	0.35	0.07	0.35
Bright	1.0	0.2	1.0

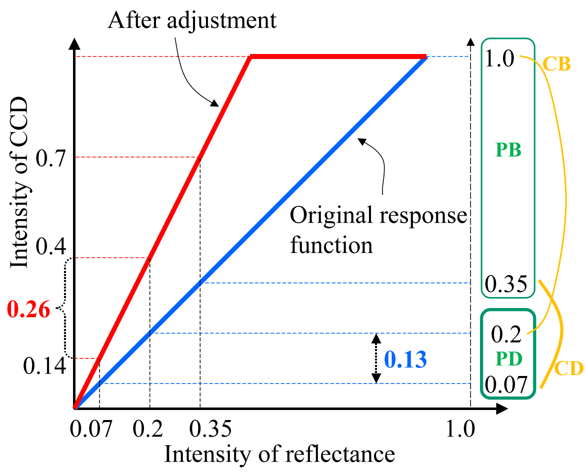


Figure 3: Response function.

possible to distinguish the other pattern. To realize efficient decomposition, different gray color values are assigned for the board and the projector as shown in Table 1. Since intensity of reflected color is proportional to a multiplication of incident light and surface color, SN ratio of dark region is worse than bright region as shown in Fig. 3(blue line). For solution, we intentionally use the saturation of CCD rather than avoid it to create non-linearity of response function as shown in Fig. 3(red line). We can confirm that minimum difference value between colors is doubled from 0.13 to 0.26.

4.2. ADAPTIVE BINARIZATION FOR THE FIRST PATTERN

Figure 5(a) and 6(a) are examples of captured images. Since intensities of the patterns are intentionally biased, we can observe four different colors, which is a combination of two colors from board and projection, respectively. Although there are four colors, we can set the specific threshold to separate the pattern; note that it is possible only for one of two patterns, which can be easily understood by right-axis in Fig. 3. In addition, since the orientation of the planar board is widely changed at each capture, the captured image has uneven brightness especially when a direction of the surface becomes parallel to the view direction. Therefore, if the binarization was processed with single threshold for the entire image, the process will fail as shown in Fig. 5(b).

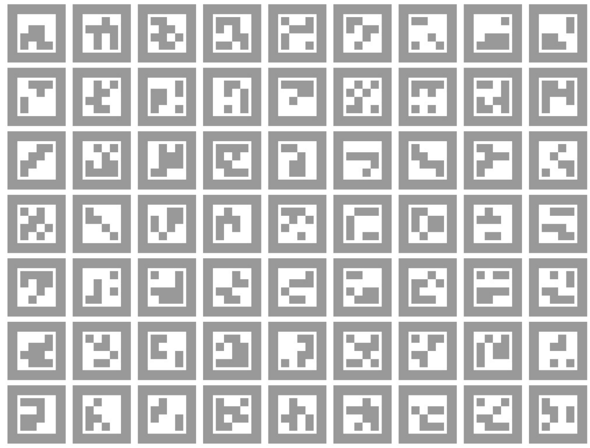
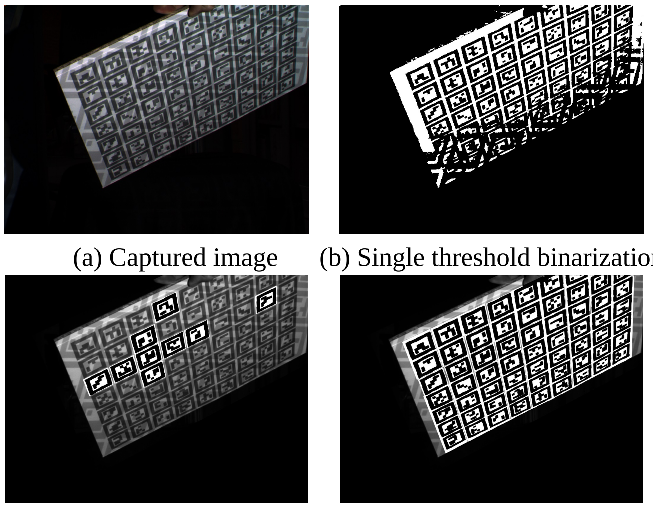


Figure 4: Calibration patterns with our original AR markers.



(a) Captured image (b) Single threshold binarization

(c) Initial detection from (b) (d) Final detection result.

Figure 5: Iterative process of adaptive binarization method.

To solve this problem, adaptive binarization method is proposed. Specifically, after extracting the small number of AR markers with global threshold, adaptive binarization is carried out by individually binarizing each marker. The positions of each marker can be localized by using the board position in 3D space, the position is estimated by the initially retrieved small number of markers. Note that a simple adaptive approach such as dividing the image into rectangular blocks usually fails because of drastic change of brightness on the board. As shown in Fig. 5(c), we can detect only 9 AR markers from the initial binarization result of Fig. 5(b). However, using the valid AR markers in Fig. 5(c), the area was expanded and binarization was successfully performed over the entire field as shown in Fig. 5(d).

4.3. SECOND PATTERN DETECTION BY GLOBAL OPTIMIZATION

Unlike the first pattern, the second pattern theoretically cannot be binarized by a single threshold; the reason can also be understood by right-axis in Fig. 3. To solve the problem, we propose a technique utilizing the first pattern binarization result with the following approach. We first make two masks for both negative and positive side from the first binarization result as shown in Fig. 6(b). Then, we apply the masks to original image to decompose the image into two as shown in Fig. 6(c) and (d), respectively; note that binarization is possible with a single threshold on those decomposed images. To improve the result, we also apply the adaptive binarization method. Results are shown in Fig. 6(e) and (f). Finally, the two images are merged into one as shown in Fig. 6(g). Since the image contains considerable errors especially near the boundary of the pattern, graph cut(GC) is conducted for refinement [7]. Then, AR markers are detected from the image and the result is shown in Fig. 6(h).

5. CALIBRATION

5.1. ESTIMATION OF THE INITIAL PARAMETER

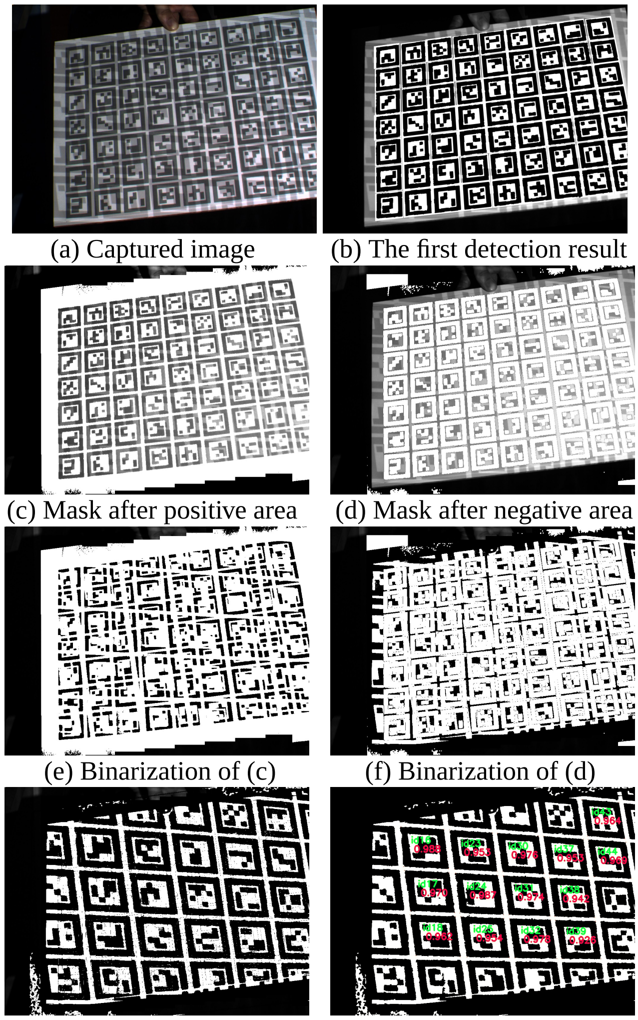
The intrinsic calibration of the camera is the same as Zhang's method. The intrinsic calibration of the projector is conducted according to the 3D position of AR marker calculated by the result of the camera calibration. The extrinsic parameters are also obtained through the process, however, the estimated parameter here is redundant since they are independently estimated for the camera and the projector. Therefore, they are used as the initial value to re-estimate the precise parameter as explained in the next section.

5.2. ACCURATE ESTIMATION BY BUNDLE ADJUSTMENT

If we have n images for input, the number of the extrinsic parameter, which includes three for rotation and three for translation for each, is $2 * 6n$. However, since the relative position between projector and the camera are fixed, not all parameters are independent and the number of unknown parameter is $6n + 6$. With such condition, parameters are efficiently optimized by using the bundle adjustment. In addition, the proposed method optimizes the focal length of the camera and the projector (four parameters) at the same time. Therefore, the number of parameter is $6n + 6 + 4$. The sum of the reprojection error for the camera and the projector is calculated by the following equation.

$$E = \sum_{i=0}^{n} \sum_{a=0}^{p} (E_c + E_p), \tag{1}$$

where n is the number of images, p is the number of unique points, E_c is the reprojection error of the camera, and E_p is the reprojection error of the projector. With this method, since the position between the camera and the projector can be estimated as the consistent parameters, accuracy and stability of the calibration are greatly improved.



(a) Captured image (b) The first detection result
(c) Mask after positive area (d) Mask after negative area
(e) Binarization of (c) (f) Binarization of (d)
(g) Merged image before graph cut (h) After graph cut

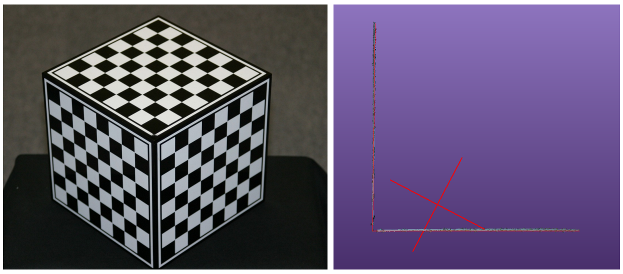
Figure 6: The second pattern binarization result with graph cut.

6. EXPERIMENT

First, we recover the shape of box with 90 angles as shown in Fig. 7(a). The calibration result that used the special calibration box with Gray code pattern was used as the ground truth. The reconstruction result is shown in Fig. 7(b) and the numerical results are shown in Table 2. We can confirm that our method is almost same as the ground truth.

Next, detection and identification accuracy were compared to original AR marker shown in Fig. 2(a). As shown in Table 3, although there is a little difference on detection number, we can confirm that identification accuracy is greatly improved with our marker.

Finally, we test the effectiveness of the proposed method



(a) 90 angles box (b) Reconstruction result

Figure 7: Comparison of the accuracy of the calibration box.

with various conditions using the same pattern; 1) without adaptive binarization using single threshold, 2) our adaptive binarization without graph cut, 3) adaptive binarization with predefined 2D block with graph cut and 4) our binarization method with graph cut. As shown in Table 4, we can confirm that adaptive method greatly increases the detection number and improves calibration accuracy. We can also confirm that if we have enough number of input such as 40, all the adaptive methods realize enough quality, whereas only our method can achieve high quality with small number such as 20.

Table 2: Shape accuracy compared to ground truth.

	angles(degree)	RMSE(mm)
Grand truth	89.95	0.67
Ours	89.70	0.56

Table 3: Results of marker detection and identification.

	Num. of shots	Num. of detection	Num. of correct ID $C > 0.8$	$C > 0.9$
Original AR	40	2,144	1,636	583
Optimized AR	40	2,337	2,298	1,204

* C denotes the confidence ratio, larger than 0.9 is preferable.

7. CONCLUSION

In the paper, we propose a practical and accurate calibration method using monochrome AR markers. Since it is not required to detect entire pattern for calibration, freedom on configuration of camera and projector and movement of planar board is greatly improved, resulting in fast and easy data acquisition process, which realizes accurate calibration. Experiments were done to show the successful results on calibration. In the future, calibration of multiple sets is planned.

Table 4: Comparison of different input numbers.

	1) Single threshold	2) Proposed (w/o GC)	3) Block (with GC)	4) Proposed (with GC)
Shots	40	40	40	40
Detect pts.	321	1,316	1,327	1,741
RMSE(mm)	4.61	0.62	0.60	0.62
90 deg.	28.166	90.99	90.82	90.41

	1) Single threshold	2) Proposed (w/o GC)	3) Block (with GC)	4) Proposed (with GC)
Shots	20	20	20	20
Detect pts.	77	131	295	627
RMSE(mm)	20.40	1.02	1.05	0.70
90 deg.	156.80	79.44	85.90	90.04

ACKNOWLEDGMENT

This work was supported in part by Funding Program for Next Generation World-Leading Researchers No.LR030, Grant-in-Aid for Scientific Research No.24500120 in Japan.

REFERENCES

[1] H. Kato and Mark Billinghurst, "Marker tracking and hmd calibration for a video-based augmented reality conferencing system," in *Proceedings of the 2nd International Workshop on Augmented Reality (IWAR 99)*, San Francisco, USA, Oct. 1999.

[2] Ryo Furukawa and Hiroshi Kawasaki, "Uncalibrated multiple image stereo system with arbitrarily movable camera and projector for wide range scanning," in *IEEE Conf. 3DIM*, 2005, pp. 302–309.

[3] Makoto Kimura, Masaaki Mochimaru, and Takeo Kanade, "Projector calibration using arbitrary planes and calibrated camera," in *IEEE CVPR Workshop on Projector-Camera Systems (ProCams)*, 2007, vol. CD-ROM, pp. 1–1.

[4] Shota Kiyota, Hiroshi Kawasaki, Ryo Furukawa, and Ryusuke Sagawa, "Efficient projector calibration method using plane with checkerboard pattern," in *Information Processing Society of Japan (IPSJ) Technical Report*, 2012, vol. 2012-CVIM-180, pp. 1–8.

[5] Samuel Audet and Masatoshi Okutomi, "A user-friendly method to geometrically calibrate projector-camera systems," in *The 6th IEEE International Workshop on Projector-Camera Systems(Procams2009)*, 2009.

[6] Jamil Draréni, Peter Sturm, and Sébastien Roy, "Projector calibration using a markerless plane," in *Proceedings of the International Conference on Computer Vision Theory and Applications, Lisbon, Portugal*, feb 2009, vol. 2, pp. 377–382.

[7] Yuri Boykov, Olga Veksler, and Ramin Zabih, "Efficient approximate energy minimization via graph cuts," *IEEE transactions on Pattern Analysis and Machine Intelligence*, vol. 20, no. 12, pp. 1222–1239, November 2001.