A Calibration Method for
Large-Scale Projection Based Floor Display System

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ABSTRACT

We propose a calibration method for deploying a large-scale projection-based floor display system. In our system, multiple projectors are installed on the ceiling of a large indoor space like a gymnasium to achieve a large projection area on the floor. The projection results suffer from both perspective distortion and lens distortion. In this paper, we use projector-camera systems, in which a camera is mounted on each projector, with the "straight lines have to be straight" methodology, to calibrate our projection system. Different from conventional approaches, our method does not use any calibration board and makes no requirement on the overlapping among the projections and the cameras' fields of view.

Keywords: Large-scale projection; projector-camera system; lens distortion; calibration; augmented reality.

Index Terms: •Human-centered computing~Displays and imagers • Human-centered computing~Mixed / augmented reality • Computing methodologies~Camera calibration

1 INTRODUCTION

We deployed a large-scale floor projection system in a school gymnasium. One task in constructing a projection system that targets a large-scale space is to calibrate multiple projectors to align the projected images into one large projection. In our case, it is impossible to use chessboard based calibration method such as[3] to calibrate the system due to the large working distances of the devices. Self-calibration methods[4] also not work in our situation, because the number and locations of devices are usually limited by factors of realistic environment such as building structure, weight capacity and original purpose of the facility, therefore the projections and cameras' field of view are not sufficiently overlapped to generate reliable correspondences among devices. In this paper we introduce the calibration procedure we used on our projection system. We make use of projector-camera sets and "straight lines have to be straight"[2] methodology. Our calibration method does not require significant overlapping among projections, therefore, the number of projector can be minimized.

2 SYSTEM SETUP

As shown in Figure. 1, our projection system consists of multiple projector-camera systems with cameras mounted on top of the projector. This system is installed on the ceiling and content is presented on the floor. The total projection area of our system is

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around $120m^2$, and it can be extended by simply adding more projector-camera sets.

3 CALIBRATION METHOD

Camera lens distortion correction: Basing on "straight lines have to be straight", the optimal lens distortion parameters can be found by minimizing the degree of distortion of straight lines in an image. In our method, we evaluate the degree of distortion for each line using the covariance matrix of their sample points. In case that there is no sufficient straight line in the camera view, we can use laser line pointer to project some straight lines on the projection plane. The optimization is done by an algebraic approach proposed by Alvarez [1].
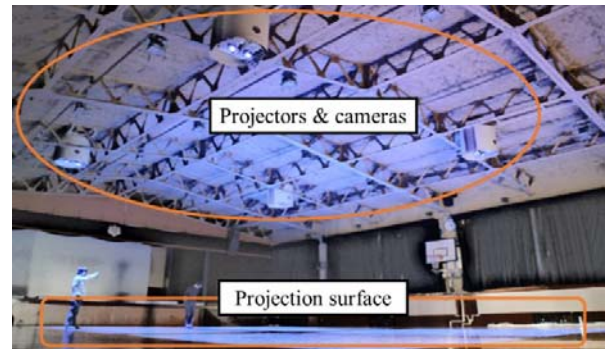

Figure 1: Large-scale projection system comprised of multiple projector-camera systems

Projector lens distortion correction: We first use the projector to be calibrated to project some straight lines on the projection plane. Then we use the camera, which has been calibrated by the above procedure, to capture the projection result and evaluate the degree of distortion of the projected image. The distortion parameters of a projector can be then optimized by Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm, which iteratively finds the optimal values that produce the least distorted result in the camera image. To improve the accuracy and efficiency, the initial value of distortion center is roughly estimated by finding the intersection of the least distorted row and the column before optimization. Furthermore, to avoid projecting several patterns pre-wrapped by new parameter values in each iteration, which is very time-consuming, we use *line-shift* structured light to generate the projector-to-camera pixels correspondences for each projector-camera set with sub-pixel accuracy in advance. Doing this, for any further projections, we can get a camera coordinate in sub-pixel accuracy for every projector pixel, so that we can simulate the projecting and capturing in each iteration instead of performing them in the real world and thus reduce the processing time.

Projective distortion correction: As the lens distortions have been corrected, the projective distortion can be corrected by pre-wrapping the projector buffer by the projector-to-floor homography
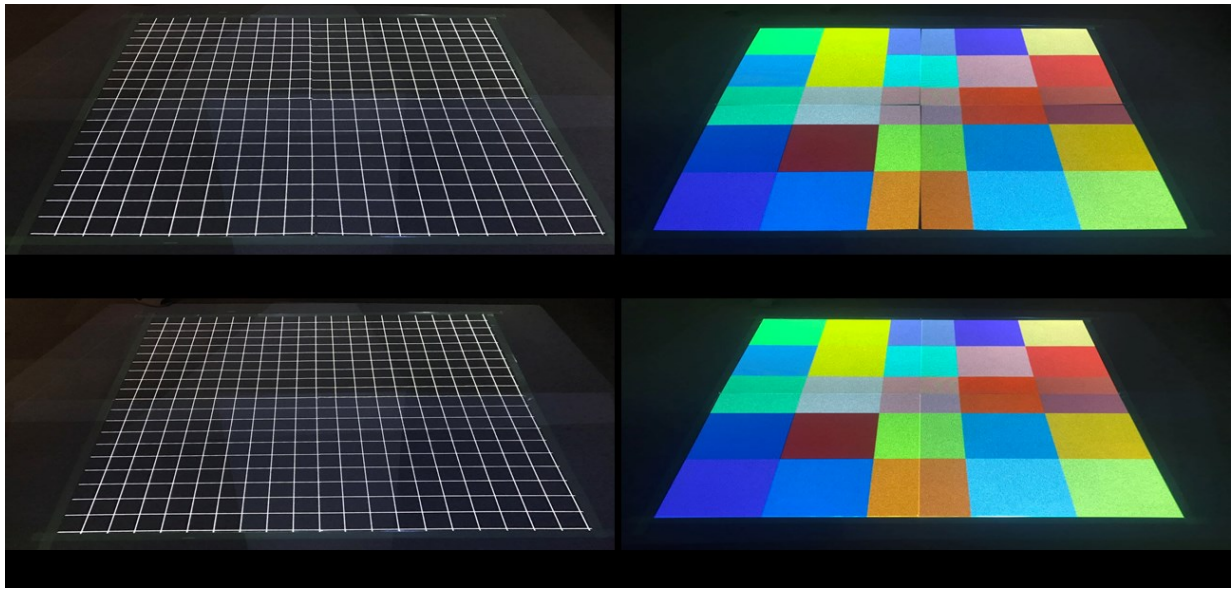
Figure 2: (a) and (b): Projection results of line grid and color block with only projective distortion correction. (c) and (d): The results with both projective distortion and lens distortion.

H_{pf}. This homography is calculated from the projector-to-camera homography H_{pc} and the camera-to-floor homography H_{cf}. H_{pc} can be estimated by finding the coordinate correspondences between the projector and the camera, and similarly, H_{cf} can be estimated by finding the coordinate correspondences between the camera and the floor.

4 EXPERIMENTS

4.1 Quantitative experiment

We performed a quantitative experiment by simulation. We generated three projector camera coordinate maps with white noise [-0.1,0.1], [-0.3,0.3] and [-0.5,0.5] (unit: pixel). The ground truth values and calibration results based on these three maps are shown in Table 1.

Table 1: Projector lens distortion estimation results

Variables	k_1' (1e-7)	k_2' (1e-14)	Distortion center (unit: pixel)
Ground truth	-1.023	4.387	(512, 384)
Noise = ±0.1	-1.025	4.428	(512.104, 383.858)
Noise = ±0.3	-1.024	4.404	(511.214, 383.966)
Noise = ±0.5	-1.012	4.138	(512.726, 384.681)

Both k_1' and k_2' are converging to the ground truth, while k_2' is less stable because its effect on the lens distortion is much weaker than k_1'. The estimation errors of the distortion center for all three maps are less than 1 pixel.

4.2 Projection Experiment

In this experiment, we use four projectors whose projections are approximately aligned on the floor. We projected two kinds of images to evaluate the appearance of the projection result: a grid pattern that only consists of 1-pixel lines and a color block pattern. Figure 2(a) shows that for the line grid image, some lines are bent, and noticeable line misalignments occurred around adjacent edges between two projections. Figure 2(b) shows that for the color block images, the gap between two projections is much more obvious than line bending and misalignment. Note that since adjacent edges

are curved, the gaps cannot be solved by linear transformation. Figure 2(c) and 2(d) give the corrected results of the line grid as well as the color block generated by our method. In these results, distorted lines are straightened, and misalignment and gaps around adjacent edges can barely be observed. Although it is not seamless since there is very narrow overlapping between two adjacent projections where the projection intensity is higher than the surrounding areas, the problem can be solved by additional intensity normalization.

5 CONCLUSION

In this paper, we proposed a calibration method for a projector-camera system in a large-scale space. Using the "straight lines have to be straight" methodology, our method corrects the projective and lens distortions of both the projector and the camera without moving them or the projection plane. Although our method's optimization is based on projecting and capturing iterations, which is time-consuming, by generating a projection camera pixel map in advance, projecting and capturing can be performed virtually to reduce the processing time.

The quantitative experiment shows that the estimation results of projector lens distortion parameters are very close to the ground truth values. Our projection experiment shows that compared with a result where only projective distortion correction was performed, our method gave a more seamless projection result.

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