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

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

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\textbf{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.

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

\textbf{Index Terms:} \textbullet Human-centered computing—Displays and imagers \textbullet Human-centered computing—Mixed / augmented reality \textbullet Computing methodologies—Camera calibration

\section{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\textsuperscript{[3]} to calibrate the system due to the large working distances of the devices. Self-calibration methods\textsuperscript{[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”\textsuperscript{[2]} methodology. Our calibration method does not require significant overlapping among projections, therefore, the number of projector can be minimized.

\section{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 around 120m\textsuperscript{2}, and it can be extended by simply adding more projector-camera sets.

\section{3 CALIBRATION METHOD}

\textbf{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\textsuperscript{[1]}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Large-scale projection system comprised of multiple projector-camera systems}
\end{figure}

\textbf{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 \textit{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.

\textbf{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

\begin{thebibliography}{9}
\bibitem{1} Alvarez, J., \\
\bibitem{2} Kenji@iit.tsukuba.ac.jp
\end{thebibliography}
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

<table>
<thead>
<tr>
<th>Variables</th>
<th>$k_1$' (1e-7)</th>
<th>$k_2$' (1e-14)</th>
<th>Distortion center (unit: pixel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground truth</td>
<td>-1.023</td>
<td>4.387</td>
<td>(512, 384)</td>
</tr>
<tr>
<td>Noise = ±0.1</td>
<td>-1.025</td>
<td>4.428</td>
<td>(512.104, 383.858)</td>
</tr>
<tr>
<td>Noise = ±0.3</td>
<td>-1.024</td>
<td>4.404</td>
<td>(511.214, 383.966)</td>
</tr>
<tr>
<td>Noise = ±0.5</td>
<td>-1.012</td>
<td>4.138</td>
<td>(512.726, 384.681)</td>
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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 performance 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.

4.3 The results of line grid and color block with only projective distortion correction. (c) and (d): The results with both projective distortion and lens distortion.

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.

REFERENCES