

# Autonomous Constructing Everyday Projected Displays

Cui Xie, Qi Wang and Wei Cheng

Department of Computer Science, Ocean University of China, 238 Songling Road, Qingdao, China

**Keywords:** Projector-based Display, Image Warping, Automatic Geometric Correction, Non-Planar Surface.

**Abstract:** This paper presents an autonomous geometric correction method to support constructing a projector-based large display for everyday use, which includes offline and online processing phase. The offline process is focus on an automatic, fast and robust approach for the geometric registration of projector-camera system. The online stage is mainly the implementing real-time image warping via modern graphics hardware to achieve the final corrected images without first acquiring geometric information of the screen's surface. Since a simple checkerboard pattern is used to facilitate building the mapping of the corner correspondences of projector-camera image, and a perspective projection invariant rational Bezier patch is used to approximately represent the mapping, our method saves a lot of computing time and become easier and robust. Therefore, the achieved transformation can be used for online image warping for actual projection. As a result, a layman user can get a corrected image displayed on a non-planar surface for the point of view of the camera easily.

## 1 INTRODUCTION

Portable projectors have become increasingly cheaper, brighter, and smaller. So, projectors have been widely used as a display tool for many applications, such as offices, classes, research institutes and for home entertainment (Jiang, 2007). Moreover, multi-projector based displays can provide seamless display with greater view angle, higher resolution and immersive experience than other traditional display technologies. So, many researches are focus on how to create projector-based large displays automatically and quickly.

In most projection-based displays, users have to deal with the geometric distortion of the projected image when the projector is located far from the observer and/or when the 3D screen surface is badly oriented. By camera-based computer vision techniques, one solution is to do complex geometric registration including camera/projector calibration and 3D screen surface recovering to wrap the projected image for any viewpoint (Sajadi, 2010). These classes of automatic methods can be achieved in different ways. Homography based method is feasible for constructing large display over flat surfaces (Chen, 2002); (Raij, 2004); (Jiang, 2007); (Brown, 2002); (Damera-Venkata, 2007). Structured

light patterns are often used for nonplanar display, which uses a large number of pre-designed patterns of light to encode the correspondence pixel position of the camera and the projector, and then achieve the geometric registration (Tardif, 2003); (Raskar, 1999); (Aliaga, 2008). However this method is complex and time-consuming. Raskar et al. in (Raskar, 2004) use a stereo camera pair to reconstruct quadric surfaces and propose conformal mapping and quadric transfer to minimize pixel stretching of the projected images. The non-linear optimization of estimation of the parameters of quadric transfer is too time-consuming. Recent work of Sajadi et al. (Sajadi, 2011) have shown that it is possible to register multiple projectors on non-planar surfaces using a single uncalibrated camera instead of a calibrated stereo pair when dealing with vertically extruded surfaces. Both above methods make its wide application limited to a series of special non-planar planes.

An easier way is directly to do geometric registration by establishing correct projector-camera matches relative to the observer (Tardif, 2003). Unfortunately, due to the non-linear color distortion of the camera, noise and the complex illumination conditions, pure color-based matching strategies between the images of projector and camera are usually fail. Sun et al. (Sun, 2008) proposed a robust checkerboard pattern recognition

method to help non-planar surface geometry registration. Sun's method considers both the geometric and the color feature of the checkerboard internal corner, and showed more robustness and effectiveness than existing corner detection method, such as Harris, SUSAN, and FAST.

In this paper, we propose an easy way to automatically build a correct projected display for everyday users. Our method is motivated by Sun (Sun, 2008), which use a robust checkerboard pattern recognition method to build the projector-camera matches. But different from Sun's method that using many planar quad patches to approximate the nonplanar surface and use homography to represent the mapping between camera and projector correspondences, our method use rational Bezier patches to approximately represent the mapping from camera and projector, which considers the nonlinearities of projector or camera and achieve faster and more robust matching.

## 2 OVERVIEW OF OUR SYSTEM

The proposed system includes one or more commodity projector for receiving images from the computer. A common camera is employed to capture the projected image of projectors and stand for the position of the viewer. Our method is based on the following four steps, which can be further divided into offline and online processing stages. The offline stage includes the first three steps and the last one is the real-time stage. More details will be described in sec. 3.

- 1). Start projecting and capturing the checkerboard pattern and detect checkerboard internal crossing corners.
- 2). Find camera-projector matchers and build the transformation  $R$  based on the corners correspondences.
- 3). Build the similarity transformation  $S$  by corners correspondences and define the spatial transformation  $W=R*S$  for image warp.
- 4). Using the transformation  $W=R*S$  to correct the geometry of the input image and get the corrected image for the viewer.

## 3 DETAIL OF OUR METHOD

### 3.1 Checkerboard Corner Detection

Considering the distortion of the curved surface,

the quality of the camera and the complex illumination condition etc., we choose to use the checkerboard corner detection method of Sun's (Sun, 2008) with some implementation changed and improved. For each pixel  $P$ , check it's neighbours' surrounding layer's points within a rectangular window(see figure 1). If most of the surrounding layers with four black and white intensity shifts, the detected point is a candidate corner. Then, we refine the corner position with a cluster method to merge all the detected candidate corners that are close to each other. Figure2 (a,b,c) illustrates the detected corners (record as corners collection  $N$ ) after clustering with our method.

In order to show the robustness of the corner detection method, a computer generated source checkerboard pattern(see figure 3a) is projected on an arbitrary surface and is captured by a general low-cost cameras for corner detection test. Do the above coner detection processing and Opencv's (FindChessboardCorner function) (Noah, 2009) respectively. It is easy to note that our corner detection result (figure 2(a,b,c)) is better than Opencv's result (figure 2(d,e,f)) even with bad illumination condition and distinct nonplanar surface deformation.

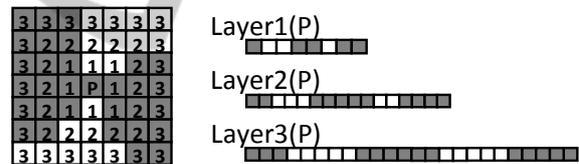


Figure 1: Corner  $P$ 's surrounding layers and their four black and white intensity shifts.

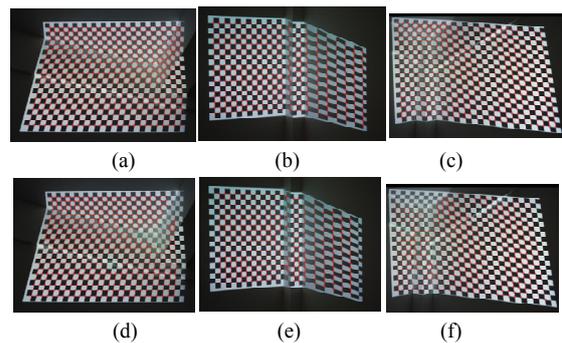


Figure 2: Our corners identified result(a,b,c) comparison with OpenCV's (d,e,f).

### 3.2 Corners Matching

In order to recognize the captured checkerboard pattern, we need to connect the corners into quad

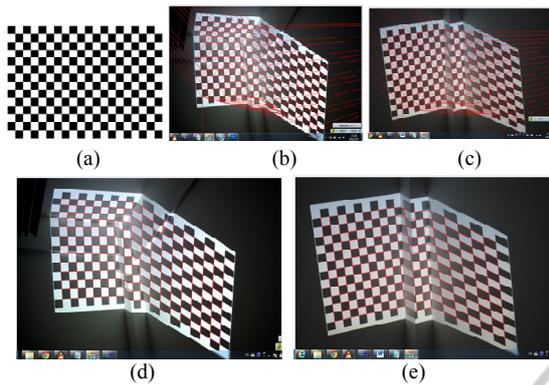


Figure 3: A source checkerboard pattern generated by a computer(a), delaunay triangulation result (b,c) and regular quad meshes(d,e).

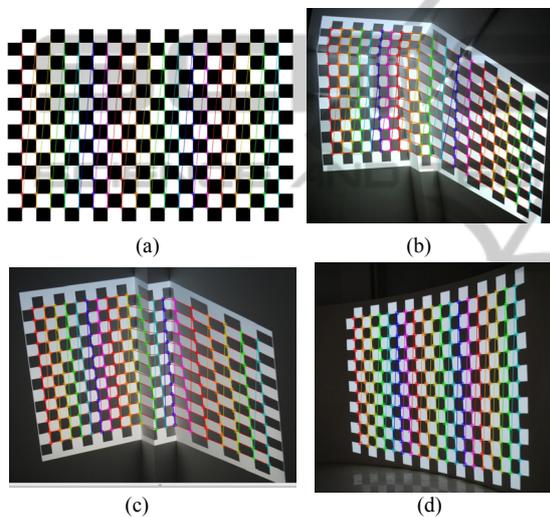


Figure 4: The recognized corners are connected with lines in column order in source checkerboard pattern(a) and projected checkerboard pictures (b,c and d).

meshes and build the corners matching between the computer generated checkerboard pattern and the projected checkerboard pictures captured by a camera. Here we only consider the grids inside the checkerboard(see figure4a). First, use the delaunay triangulation method described in the OpenCV library to connect all the detected corners (see red lines in figure 3(b,c)). Then we do edge filtering to remove the redundant or illegal edges and get a regular quad meshes.

There are two classes of false edges: first is the edges crossing the background or go through more than one quad, and the second class is the diagonal of each quad. For the first class of false edges, we use a distance threshold to determine a false edge and remove it. As for the second class of false edges, we check for the average color around the detected

edges. If the color on both sides of the edge is similar, it is the redundant edge and should be removed. Otherwise keep it. Figure 3(d,e) shows the quad meshes after false edges filtering and a graph  $G(N1,E)$  with a regular grid topology is achieved. The next step is to map nodes of the grid to the corners of the pattern.

To do corner matching, from the upper left the first corner, according to the column coordinates order, using topological information, the coordinates labelling can be done easily. Figure 4 gives the experiment results of the ordered and connected corners of source checkerboard pattern and projected checkerboard respectively. Each color represents a column of corners and the last corner of one column is connected to the first corner of next column. From the result, we can see that the algorithm can correctly recognize the checkerboard corners on deformable non-planar surfaces and thus the corners correspondence is built.

### 3.3 Constructing Correspondences Mapping R and R-1

Based on the corner correspondences obtained form section 3.2, Our method fit a rational Bezier patch using a non-linear least squares fitting technique to build the mapping R between these correspondences from camera image to projector image. The following experiment results illustrate the effectiveness of our method.  $R^{-1}$  means the mapping from projector image to camera image. To be more efficient, mappings between each corresponding point pair can be pre-computed and stored as a pixel mapping look-up table for online efficient geometric correction will be more convenient.

### 3.4 Determining Valid Target Display Area and Similarity Transformation S

In order to show the image on a non-planar surface in an undistorted view with respect to the viewer, a new proper display area(as is shown in figure 5b) used for projection of the corrected image, with the largest possible size, should be defined on the inside of the captured uncorrected image. Actually, we use a simple and approximative method to find a maximum rectangular area within the covered area of the projector into the camera image. This rectangle has the same ratio as the initial source image and has the same center of gravity as the coverage polygon of the camera image. Then the expected rectangle can be horizontally and vertically

extended starting from the center of the coverage polygon until one of the corners of the rectangle reaches the boundary of the coverage polygon. The red color box of figure 5b shows the valid area used for actual projection.

Once the target display area is determined, the correspondences of the corners to the source image are obtained from a similarity transformation  $S$ , which defines how the source image to be geometrically corrected in the target area of the camera image. The similarity transformation  $S$  includes a translation and a scale transformation between the target display area and the input image. Figure 6 shows that the original detected corners are transformed by  $S$  into the target rectangle as red points.

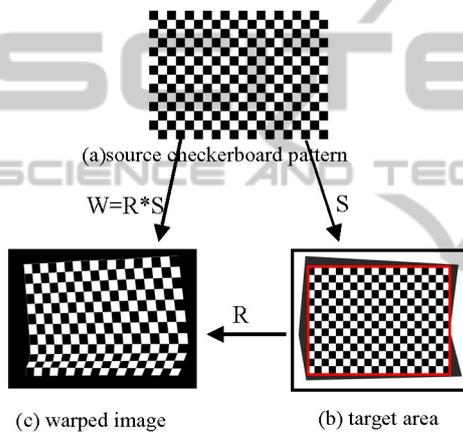


Figure 5: The valid target rectangle area and corners are transformed into the target rectangle by  $S$ .

### 3.5 Defining Spatial Transformation

The spatial transformation from the source image (figure 5a) to the target output image (figure 5b) must be pre-defined to execute a pre-compensating inverse distortion (figure 5c) for geometry correction. #

(1) First, do similarity transformation  $S$  between the target rectangle and the source input image to scale and translate the detected corners into the valid image area (see figure 5b and figure 6 (b,d)).

(2) Then, apply the transformation  $R$  to the corners of the first processing result and get the warped transformation  $W=R*S$  (figure 5), which maps the each source corner to the specific target point (see figure 6 e and f). To be more efficient, mappings between each corresponding point pair can be stored as a pixel mapping look-up table for online efficient geometry correction.

### 3.6 Online Geometric Correction

Based on hardware-accelerated computer graphics and combined with an OpenGL texture mapping technology (see figure 7), the final corrected image warped by  $W=R*S$  can be rendered in real-time and projected on the screen with visual correct effect.

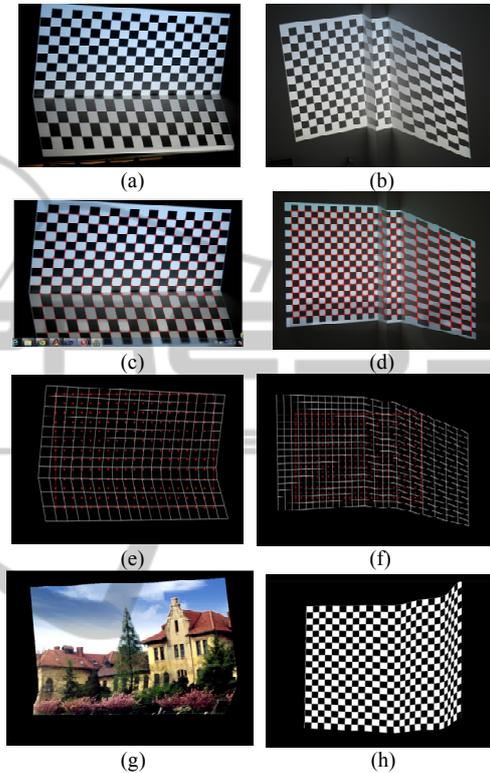


Figure 6: (a and b) are camera image, (c) is corners detection result and (d) is quad meshes. (e, f) show the valid target rectangle area and corners are transformed into the target rectangle by  $S$ . (g and h) are warped image with texture mapping by transformation  $R*S$ .

## 4 EXPERIMENT

### 4.1 Geometric Correction with Single Projector

To test our method, we first use one projector and one camera to build a simple projector-camera system. To simplify the experiment, we set the viewer and the calibration camera to be the same position and we can ignore the transformation between camera and viewer.

Firstly, a checkerboard pattern with resolution  $1024 * 768$  is generated by our computer. Then it is projected with same resolution on a cylinder screen

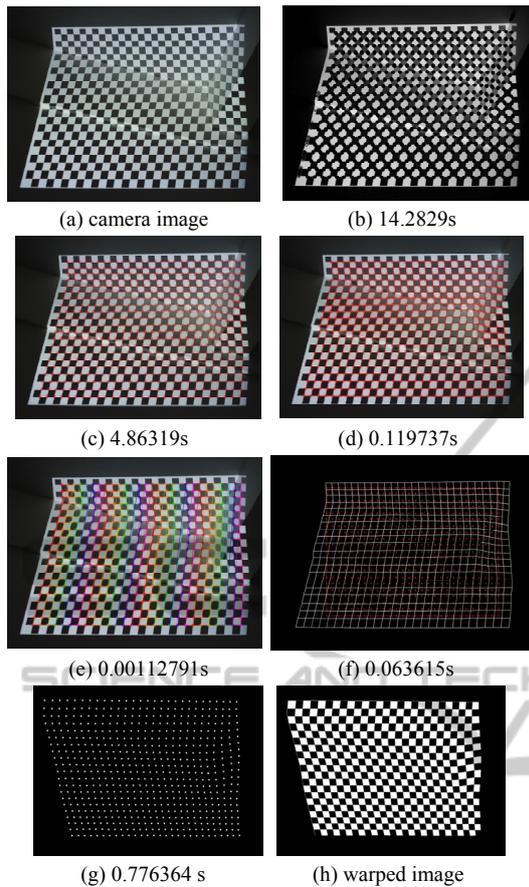


Figure 7: The computing time spend on each processing step of our method from (a)the camera captured image to (h)the warped image: (b)corner detection result, (c) corners clustering, (d)quad meshes,(e)corners ordering and checkerboard recognition, (f) valid display rectangle and similarity transformation, (g) spatial transformation of corners for geometry correction, and (h) warped image result.

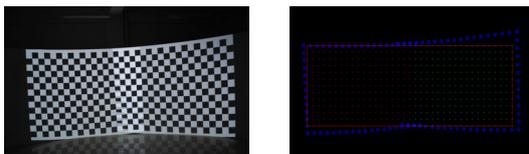


Figure 8: Two projectors Figure 9: The valid rectangle covered area.

and is captured by a camera. Here all the images in our experiment are pre-processed into size of 1024 \* 768 resolution. In figure 7, the computing time used for each processing step is shown.

Using a computer with an Intel Core 2 Duo 2.13 GHz CPU and a 2GB RAM, our implementation achieved a recognition speed of 15.52s for a 19\*13 checkerboard pattern and 19.26s for a 28\*21

checkerboard pattern.

## 4.2 Geometric Correction with Multi-projectors

In Figure 8, two projectors are used for multi-projector setup with necessary projection area overlapping. Notice that the common region is must but resulting in unwanted intensity fluctuations. We can use the intensity blending technique to remove the bright and provide a seamless correct display. To ensure good result, each projector should cover an enough large part of the camera image.

The multi-projector display uses the same geometric principles as the single projector projection. As long as the covered area projected by the projectors is visible to the camera and each projector need to decide it's own valid projection area first (see figure 9). Then, compute the individual mapping  $R$  for each separable area of the projection by corresponding feature points from the uncorrected and input images. The similarity transformation  $S$  is obtained and the transformation  $R*S$  is applied to each projector and corrected images are achieved finally (see figure10).



Figure 10: The final corrected image projection.

## 5 CONCLUSION AND FUTURE WORKS

The paper presented a simple auto-geometric correction method for constructing low-cost smart projector system, which allows projection on non-planar surface with an uncalibrated camera by a layman user. The proposed method solves two cases: single projector and multiple projectors. The rational Bezier patch is applied to estimate the mapping relationship with simple computation. The experimental results of geometry corrected projection show that the method is automatic, fast and accurate. In the future, we will focus on the universality of the correction algorithm. The

corner-detection time could be decreased using improved algorithm.

## REFERENCES

- Jiang Z., Luo X., Mao Y, et al. ,2007. Interactive browsing of large images on multi-projector display wall system[C]. *Proc. The 12th International Conference on Human-Computer Interaction*. LNCS, vol. 4551,pp. 827-836.
- Brown M. S. and Seales W. B., 2002. A Practical and Flexible Tiled Display System. In *Proc of IEEE Pacific Graphics*, pp. 194–203.
- Damera-Venkata N., Chang N. L., and DiCarlo Jeffrey M., 2007.A Unified Paradigm for Scalable Multi-Projector Displays[J]. *IEEE Transactions on Visualization and Computer Graphics*, 13(6), pp.1360-1367.
- Tardif J.-P., Roy S., and Trudeau M., 2003. Multi-projectors for arbitrary surfaces without explicit calibration nor reconstruction. In *Proceeding of Fourth International Conference on 3-D Digital Imaging and Modeling*, pp.217-224.
- Raskar R., Brown M. S., Yang R., Chen W.-C., Welch G., Towles H., Seales B., and Fuchs H., 1999. Multi-projector displays using camera-based registration. In *Proceedings of the 10th IEEE Visualization 1999 Conference (VIS '99)*. Washington, DC, USA.
- Raskar R., J. Baar V., Willwacher T., and Rao S., 2004. Quadric transfer function for immersive curved screen displays. *Eurographics*.
- Aliaga D. and Xu Y., 2008. Photogeometric structured light: A selfcalibrating and multi-viewpoint framework for accurate 3d modelling. *Proc. of IEEE CVPR*.
- Sajadi B. and Majumder A., 2010. Auto-calibration of cylindrical multi-projector systems. In *Virtual Reality Conference (VR), 2010 IEEE*, pp. 155 –162 .
- Sun W., Yang X., Xiao S., and Hu W., 2008. Robust checkerboard recognition for efficient nonplanar geometry registration in Projector-Camera systems. In *Proceedings of the 5th ACM/IEEE International Workshop on Projector Camera Systems (PROCAMS '08)*.
- Chen H., Sukthankar R., and Wallace G., 2002. Scalable Alignment of Large-Format Multi-Projector Displays Using Camera Homography Trees. In *Proceeding of IEEE Visualization 2002*, pages 339–346.
- Raij A. and Pollefeys M., 2004. Auto-calibration of multi-projector display walls. *Proc. of ICPR*.
- Sajadi B., Majumder A., 2011. Autocalibrating Tiled Projectors on Piecewise Smooth Vertically Extruded Surfaces. *IEEE Transactions on Visualization and Computer Graphics*, Vol. 17, NO. 9, pp.1209-1221.
- Noah K., 2009. OpenCV Tutorial 10 - Chapter 11. <http://dasl.mem.drexel.edu/~noahKuntz/openCVTut10.html>.