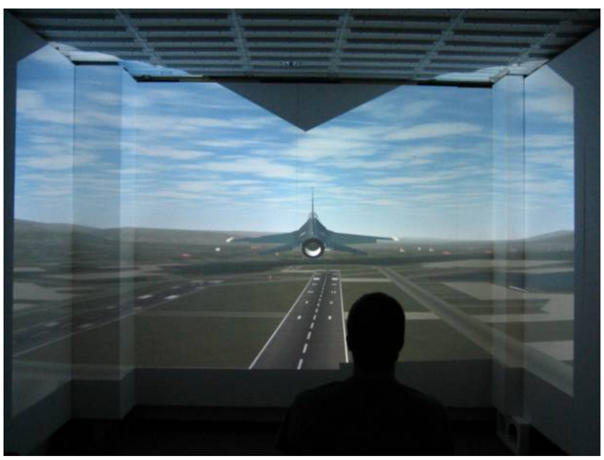
Multi-Projector Display for Wide-Area Visuals

Department of Computer Science **University of North Carolina at Chapel Hill** **March 2008**

The Challenge

Developers building multi-projector, large-format display environments have always been faced with the challenge of creating geometrically and photometrically seamless visuals. In early display systems, the developers simply restricted the optical configuration to orthogonal projection and relied on manual positioning of the projectors and external aperture masks to achieve near seamless display. Today, by using expensive custom hardware for geometry warping and electronic intensity blending, display companies can create high quality, seamless display for spherical and cylindrical-shaped display surfaces. However, the setup for these displays is still a long and arduous, interactive process.

At UNC our research focus has been on the development of automatic, camera-based calibration methods and GPU-based *warp-and-blend* rendering, which permits one to rapidly setup a multi-projector display system that can use the walls of any shaped room as the display surface.



An immersive display in a multi-wall room built with two short-throw projectors.

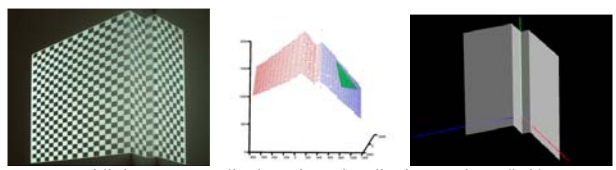
The Approach

The image distortion resulting from projecting onto surfaces more complex than a single plane can be corrected for a desired viewing location using knowledge of the display surface shape and the calibration of each projector, which includes properties such as position, orientation and the focal length of the lens encoded in a 4x3 calibration matrix.

Camera-Based Calibration. We use stereo cameras and computer vision methods to estimate the display surface geometry and the calibration matrix of each projector. By projecting structured light patterns with the projectors, we first establish image correspondences between a pair of cameras that can be used to reconstruct a 3D point-cloud representation of the display surface.

Highlights

- **Create large, immersive visuals in any room for use in virtual environments, simulation, and training.**
- **Automatic, camera-based calibration.**
- **Warp-and-blend rendering on the GPU.**
- **Interdisciplinary research involving computer graphics and computer vision.**
- **Continuous calibration allows projectors to be picked up and moved during display use.**

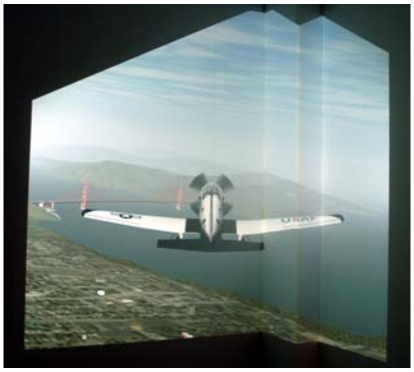


Structured light patterns displayed on the display surface (left) are used to reconstruct a point-based model of the surface (middle). Fitting planes to the points results in a polygonal surface model (right).

To construct a polygonal model from this point-cloud representation, we currently use a RANSAC plane-fitting algorithm to extract planes from the data. These planes are then intersected to form a polygonal mesh that is used during rendering to compensate for the shape of the display surface. The same 3D data along with the 2D correspondences in the projector image is also sufficient to evaluate the calibration matrix of each projector.

Warp and Blend Rendering on the GPU. Once the calibration process is complete the results are used to pre-distort the projected images by the inverse of the geometric distortion they will undergo being projected onto the display surface, and to also photometrically blend the intensity in regions of multi-projector overlap.

The geometric process occurs in two steps. In the first step, an ideal image that the viewer should observe on the display surface is rendered normally by the application. This ideal image is then pre-distorted using a rendering technique called projective texturing in which the ideal image is mathematically projected onto the polygonal model from the user’s viewpoint and rendered from the projector’s perspective (which is defined by the respective calibration matrix). This results in an image at each projector that will correctly compensate for the shape of the display surface from the perspective of the viewer. This warp-and-blend functionality is efficiently implemented as an OpenGL fragment shader.



A flight simulator in a complex room corner without distortion.

Continuous Calibration. Accurate warp-and-blend rendering is dependent on accurate estimates of the surface shape and projector calibration. Since it is not an uncommon occurrence that this is violated, e.g. a projector is intentionally or inadvertently moved, we have been developing advanced techniques for continuously estimating calibration parameters while the application is running.

We have demonstrated the ability to continuously estimate the pose of a single projector in a single or multi-projector display by observing the projected application imagery with a calibrated camera. Our technique works by predicting the images the camera will capture using the last known estimate of the projector location and uses the differences between predicted and actual camera images to determine where the projector must be using a predictor-corrector algorithm. This allows the user to intentionally pick up the projector and move it to a new location in order to, for example, increase the size of the display.

Continuous projector calibration allows the system to compensate for the new location of the projector as it is moved by the user.

Future Directions

In the future we plan to extend our initial continuous calibration results to include the ability to continuously calibrate multiple projectors simultaneously. We also hope to demonstrate the ability to dynamically compensate for the changes in the shape of the display surface. We ultimately hope to create a multi-projector display system built atop an underlying continuous calibration-rendering framework that can be configured and used by anyone. This display system would automatically compensate for projectors being moved or bumped and allow the user to dynamically incorporate new projectors without having to repeat an upfront calibration process.

Current Project Members

Henry Fuchs - (Principal Investigator), Federico Gil Professor of Computer Science
Greg Welch - Research Associate Professor
Herman Towles - Senior Research Engineer

Graduate Research Assistants

Tyler Johnson, Stephen Guy, Eric LaForce

Research Sponsors

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Selected Publications

Johnson, T. and H. Fuchs. “Real-Time Projector Tracking on Complex Geometry Using Ordinary Imagery,” *ProCams 2007,* Minneapolis, MN, June 2007.

Johnson, T., F. Gyarfas, R. Skarbez, H. Towles and H. Fuchs. “A Personal Surround Environment: Projective Display with Correction for Display Surface Geometry and Extreme Lens Distortion,” *Proc of IEEE VR 2007,* Charlotte, NC, March 2007.

Johnson, T., F. Gyarfas, R. Skarbez, P. Quirk, H. Towles and H. Fuchs. “Multi-Projector Image Correction on the GPU,” *Proc of EDGE Workshop 2006,* Chapel Hill, NC, May 2006.

Quirk, P., T. Johnson, R. Skarbez, H. Towles, F. Gyarfas and H. Fuchs. “RANSAC-Assisted Display Model Reconstruction for Projective Display,” *Proc of Emerging Display Technologies 2006,* Alexandria, VA, March 2006.

Keywords

Picture/Image Generation—Display Algorithms Three-Dimensional Graphics and Realism— Virtual reality; Computational Geometry and Object Modeling

For More Information

Herman Towles
Phone (919) 962-1784
E-mail: towles@cs.unc.edu