3DPS: An Auto-calibrated Three-Dimensional Perspective-Corrected Spherical Display

Qian Zhou[1]* Kai Wu[1] Gregor Miller[1] Ian Stavness[2] Sidney Fels[1]

[1]Dept. of Electrical and Computer Engineering, University of British Columbia
[2]Dept. of Computer Science, University of Saskatchewan

Abstract

We describe an auto-calibrated 3D perspective-corrected spherical display that uses multiple rear projected pico-projectors. The display system is auto-calibrated via 3D reconstruction of each projected pixel on the display using a single inexpensive camera. With the automatic calibration, the multiple-projector system supports a seamless blended imagery on the spherical screen. Furthermore, we incorporate head tracking with the display to present 3D content with motion parallax by rendering perspective-corrected images based on the viewpoint. To show the effectiveness of this design, we implemented a view-dependent application that allows walk-around visualization from all angles for a single head-tracked user. We also implemented a view-independent application that supports a wall-papered rendering for multi-user viewing. Thus, both view-dependent 3D VR content and spherical 2D content, such as a globe, can be easily experienced with this display.

Index Terms: H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities

1 Introduction

Spherical displays are useful for many applications, such as planetariums and virtual snowglobes, since they provide an unobstructed view from all angles. This property is ideal for creating Fish Tank VR (FTVR) [1, 2] visualizations. Using the spherical nature of the display, viewers can move around the display with head-tracking and observe a perspective-corrected scene on the spherical screen. Providing high resolution, uniformly spaced pixel imagery on the spherical screen is important for constructing spherical FTVR. One approach is to tile multiple projectors on the spherical screen to increase the resolution and make the system scalable [3]. The challenge for this lies in the stitching and blending of images from different projectors to create seamless imagery. This requires geometric and photometric calibration of the multiple-projector system.

In this work, we developed a system which consists of a spherical screen, multiple projectors and head-tracking device that enables a head-tracked user to move around and visualize 3D images with motion parallax from all angles around the spherical display. We developed an automatic calibration approach to generate seamless imagery on the spherical display from multiple projectors [4].

Using the system, we created a VR application in which a tracked user can naturally visualize static 3D models with motion parallax from arbitrary viewpoints as shown in Figure 1(right). We also created a view-independent application that makes use of the spherical shape for multi-user viewing as shown in Figure 1(middle). The results are available in the video[1].

*e-mail: qzhou@ece.ubc.ca

[1] link to the video: https://youtu.be/ut8vEyRf7N0

Figure 1: Our goal is to create a multiple-projector spherical display. We use a single camera to calibrate the multiple projector system. The calibration result is shown with a seamless grid pattern (left). For multiple viewers, we implemented a view-independent application that supports a wall-papered rendering of a rotating earth image (middle). For a single head-tracked viewer, we develop the application of spherical FTVR (right) which uses single-person perspective-corrected rendering and requires a more accurate calibration method to provide a higher quality experience to the user.

2 System Overview

The developed system includes a display system and a tracking system. The display system consists of two pico-projectors, a 29cm diameter acrylic spherical display and a chassis which holds the display surface and projectors. Projectors are set under the spherical screen, rear-projecting through a projection hole onto the screen as illustrated in Figure 2(Left). For the tracking system, we use a Polhemus Fastrak, a wired magnetic tracking system with the update rate up to 120Hz, 3msec latency and less then 0.5cm positional accuracy.

We use OpenGL to render graphics. To generate perspective-corrected images on the curved screen, we use a two-pass rendering method [5]. The two-pass rendering is chosen since the projection from 3D objects to the curved screen is non-linear. Calibration is required to make the system work.

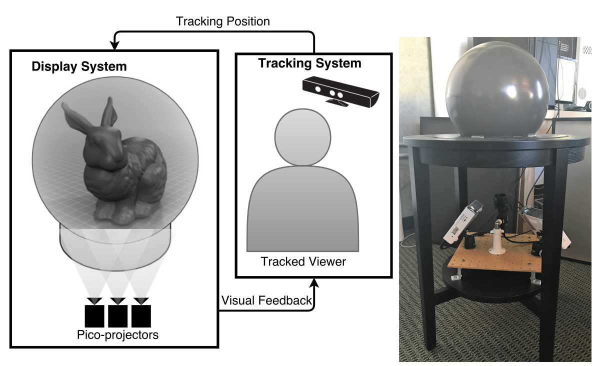

Figure 2: (Left) System diagram of a 3D perspective-corrected spherical display; (Right) System Appearance

3 Automatic Calibration Approach

To generate seamless imagery on the spherical display, we reconstruct the 3D geometry of projected pixels on sphere, which is used to register projected images and then blend the intensity in overlapping areas. The calibration approach we propose is presented in Figure 3(Left).

Camera Calibration The camera is pre-calibrated to determine the intrinsic parameters using a checkerboard-based calibration approach [6].

Pair Calibration Each projector P_i and the camera C are paired as a stereo pair S_i as shown in Figure 3(Right-top). In this step, we project blob patterns onto the spherical screen, detect them as blob features in the camera, and record feature correspondences for each pair as shown in Figure 3(Right-bottom). Using these correspondences, the fundamental matrix F_i for each pair S_i can be recovered. Then we calibrate each projector P_i by recovering its absolute dual quadric using the fundamental matrix F_i [7]. The intrinsics and extrinsics of each projector are estimated based on projected blob patterns.

Sphere Pose Estimation With the intrinsics, extrinsics and 3D points, the sphere pose can be recovered by fitting a sphere with these 3D points using a Weighted Linear Least Squares. The weighting comes from the re-projection error in the triangulation step so that a large re-projection error results in a small weight in determining the sphere pose.

Nonlinear Optimization The parameters of the sphere (pose) and the camera/projector pairs (intrinsics and extrinsics) are further refined via a nonlinear optimization to minimize reprojection error.

Ray-Sphere Intersection After refining the parameters, we compute the 3D position for each pixel on the display via ray-sphere intersection with rays coming from each projector. The geometric result for each pixel is stored in a look-up table for subsequent fast computation.

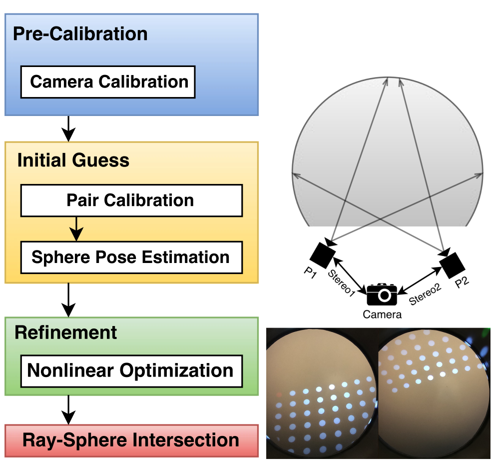

Figure 3: (Left) Calibration pipeline of a multiple-projector desktop spherical FTVR. (Right-top) Multiple-projector spherical display layout, showing overlap and approximate layout with respect to the camera. (Right-bottom) Projected blob patterns on the spherical display surface observed by the camera, for each of two projectors.

Blending For the photometric blending of the overlapping area, we compute the alpha mask for each projector based on a weighted average[5], assigning an intensity weight from 0 to 1 to each pixel in the projector. The calibration result is illustrated in Figure 1(left).

4 Application

Embodying the metaphor of a "crystal ball", the spherical display provides non-occluded views from all viewpoints around it. One of the application is to make use of its spherical shape and render wallpapered imagery on the sphere. As illustrated in Figure 1(middle), it is possible to create an application rendering planets like the earth. Multiple viewers can walk around and visualize the seamless imagery on the sphere.

For a single head-tracked viewer, we develop the application of spherical Fish Tank VR as shown in Figure 1(right). This application creates single-person perspective-corrected rendering that allows for walk-around 3D visualization with motion parallax. The viewer can naturally visualize static 3D model inside the sphere from arbitrary viewpoints. Arbitrary 3D models can be easily loaded into the scene for visualization. We believe the visualization with our spherical Fish Tank VR is a fun 3D visual experience.

5 Conclusion and Future Work

We have presented the design and applications of a spherical Fish Tank VR system. An automatic calibration approach has been developed to calibrate the system with a single camera. We implemented a view-dependent as well as view-independent application to show the effectiveness of this design. Future work will target on interaction techniques with this type of display.

Acknowledgements

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