Calibration Methods for Effective Fish Tank VR in Multi-Screen Displays

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Abstract

We present cubic and spherical multi-screen fish tank virtual reality displays that use novel interactive and automatic calibration techniques to achieve convincing 3D effects. The two displays contrast the challenges and benefits of multiple projectors or flat-panel screens, borders or borderless, and the performance of headtrackers. Individuals will be able to subjectively evaluate the visual fidelity of the displays by comparing physical objects to their virtual counterparts, comparing the two displays, and by changing the level of calibration accuracy. They will be able to test the first markerless, interactive, and user-dependent headtracker calibration that promises accurate viewpoint registration without the need for manual measurements. In conjunction with an automatic screen calibration technique, the displays will offer a unique and convincing 3D experience.

Author Keywords

FTVR; 3D display; multi-screen display; calibration.

ACM Classification Keywords

H.5.1: Artificial, augmented, and virtual realities

Introduction

Fish tank VR (FTVR) displays [9] have potential as a practical 3D display technology that can work well

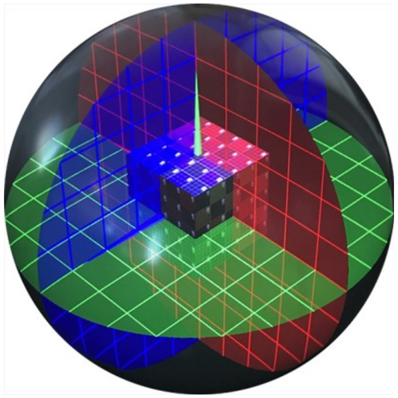

Figure 1: A spherical FTVR display after calibration with a perspective-corrected scene of intersecting planes.

Figure 2: A cubic FTVR display after calibration with a perspective-corrected scene.

within a physical work or living space. Unlike headset VR that block out a person's surrounding environment, FTVR displays can be used without glasses and naturally fit alongside traditional 2D displays. For example, in a computer-aided design scenario, orthographic views could be presented on a 2D screen while the 3D perspective view could be presented on a FTVR display.

Geometric FTVR displays, that wrap screens around a geometric shape such as box [6] or sphere [3], have the advantage of 360° viewing around a virtual object. This is particularly important for FTVR, because greater head motion enhances the motion parallax effects and improves 3D perception. A single screen FTVR display is limited to small head movements in front of the screen, as compared to walking fully around the screen or rotating a handheld display to see from any perspective.

The principal drawback of FTVR displays is that the user's viewpoint must be accurately measured in real-time with respect to each screen of the display. Even small inaccuracies in the rendered viewpoint can create visual artifacts (kinked lines, oddly floating objects, and ghosting) that can immediately and severely disrupt the 3D effect of the display. Multi-screen displays have the additional challenge that the screens and projectors must be calibrated for seamless alignment.

We have developed two new calibration methods: a camera-based fully automatic calibration method for screen-to-screen alignment, and a human perception based visual procedure for accurately determining an accurate headtracker calibration. Combined, these calibration methods enable a compelling 3D virtual reality experience using FTVR. At CHI Interactivity, we will demonstrate these advances in screen and headtracker calibration with two types of multi-screen FTVR displays: multi-projector back-projected spherical display (Figure 1) and a multi-LCD screen cubic display, seen in (Figure 2). In the demonstration, participants will experience high-resolution, high quality 3D renderings of simple and complex scenes to show how these displays can be used in a number of different application areas. They will see the difference between both low and high accuracy calibrations to subjectively evaluate the importance of calibration. Participants will experience monocular versus stereoscopic FTVR experiences as well. Participants will also compare digital objects rendered in these displays to their real life counterparts shown in adjacent display cases.

Related Work

In Augmented Reality systems, techniques exist for calibrating the viewpoint of a Head Mounted Display (HMD) to a head tracking system. The SPAAM method renders a virtual marker on a translucent HMD that viewers align with physical markers to estimate viewpoint-to-screen planar homographies [7]. Visual calibration techniques for FTVR displays involve either tedious manual tuning or visual alignment of physical and virtual markers [2]. While it is possible to perform accurate calibration using physical markers, they must be precisely constructed, measured, and placed which may clutter the area around the display. Unfortunately, these methods are incompatible with non-planar screens or non see-through displays.

The shape of a geometric FTVR display determines the appropriate method for calibrating the relative location of each screen/projector of the display. For a cubic

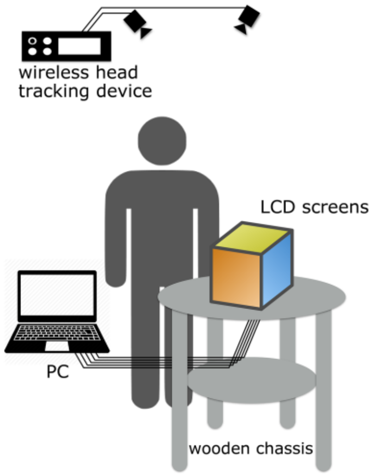

Figure 3: Cubic display setup with LCD screens.

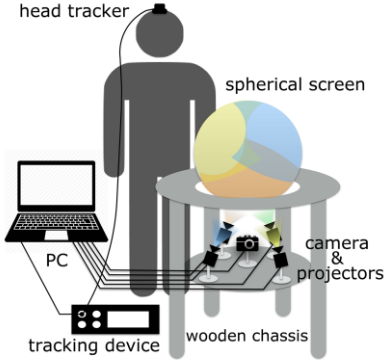

Figure 4: Spherical display setup. All projectors and cameras are mounted below the display.

display with flat screens (Figure 3), the display-to-screen transformations can be found by methods for planar geometric reconstruction such as using ARToolKit or checkerboard patterns. For a spherical display, a geometric reconstruction of the spherical display surface is needed for accurate alignment and blending of overlapping projection regions.

Physical markers have been used to approximate the geometry of curved screens to recover the transformations [H06], but must be manually placed prior to calibration and removed prior to viewing. Many existing methods have attempted to recover the 3D geometry of the screens to approximate the transformations [1], but doing so usually requires a substantial amount of manual interaction. There are techniques for camera-based reconstruction of non-planar multi-projector displays [5, 10], however, they also require many manual steps to achieve an accurate calibration, and must be repeated from the start if the display is physically disturbed. The Automatic Screen Calibration method utilized in our demonstration can automatically recover the display-to-screen transformations on a spherical FTVR requiring only a calibrated camera.

Automatic Screen Calibration

Our novel automatic calibration technique for rear projected multi-projector spherical displays only requires that a calibrated camera be placed within the rear projection space facing the projected areas. All of the projector's intrinsic and extrinsic parameters, 3D sphere pose, and screen-to-display transformations are automatically recovered from images captured by the camera as described in [11]. In this process, the camera intrinsics are calibrated in a pre-calibration step. Each projector is paired with the calibrated camera to form a stereo pair and used to project blob patterns onto the spherical screen (Figure 4). The pair is calibrated using the camera's observation of the projected pattern. Then, we triangulate to locate the blob features on the sphere. This process is repeated for each pair and the blob features are used to recover the sphere pose. These recovered parameters are further refined using a nonlinear optimization to minimize reprojection error. Finally, the 3D position of each pixel is recovered on the display surface using ray-sphere intersection. By slowing the process down, each step of the process can be visualized during the demonstration so visitors can see how each step contributes to the overall experience.

Interactive Visual Viewpoint Calibration

With FTVR displays, the viewpoint-to-screen transformations are not constant due to viewer's relative motion to the display. The viewpoint-to-screen transformations, which are necessary for perspective-correction, must be split into their constituent transformations and recovered separately: viewpoint-to-head, head-to-tracker, tracker-to-display, and display-to-screens. The head-to-tracker transformation is provided directly by the headtracker system and the Viewpoint Calibration procedure implemented with our displays can recover both the viewpoint-to-head and headtracker-to-display transformations.

Our novel pattern-based calibration, described in detail by [8], relies solely on visual cues from the display to guide the viewer into known locations while still allowing natural and unimpeded movement around the display. It renders patterns on the display such that they will appear undistorted if viewed from a known

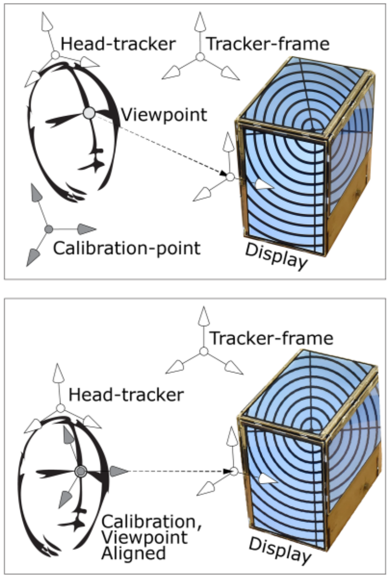

Figure 5: Viewpoint calibration: the pattern on display appears distorted when user's viewpoint is not at the correct calibration location (top), but appears correctly aligned across screens when the user aligns their viewpoint to the calibration-point (bottom).

calibration position (Figure 5). The patterns are designed so that when they appear distorted, the user can easily determine the location at which it would look correct. This process aligns a user's viewpoint to known locations relative to the display, but only the head position is recorded. This is repeated through a set of predetermined calibration positions that define a path that minimizes backtracking and maximizes workspace coverage. All the pairs of head positions and calibrations locations are used to create the viewpoint-to-head and tracker-to-display transformations. This method only requires positional information (orientation is not needed), so it works well with many types of trackers.

Summary

Multi-screen FTVR displays offer potential benefits over other conventional approaches to 3D viewing. They preserve the user's visual field and allow for seamless and simultaneous use with standard 2D displays. Since they impose few physical restrictions on the user and workspace, they can be a suitable addition to any workplace that interacts with high-quality 3D representations of data by providing relative or absolute scale and proportions. Geometric FTVR displays crucially depend on accurate multi-screen calibration and accurate viewpoint-to-display tracking. Our displays utilize novel calibration techniques that recover all required transformations and highlight the importance of accurate calibration. Participants at our exhibit will be able to easily create a personalized calibration that will enable high quality perspective-correction on our FTVR displays. They will be able to judge for themselves how compelling or convincing the 3D effects are, and learn about the importance of fast and accurate viewpoint registration in FTVR systems.

Acknowledgements

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